FIG. 1

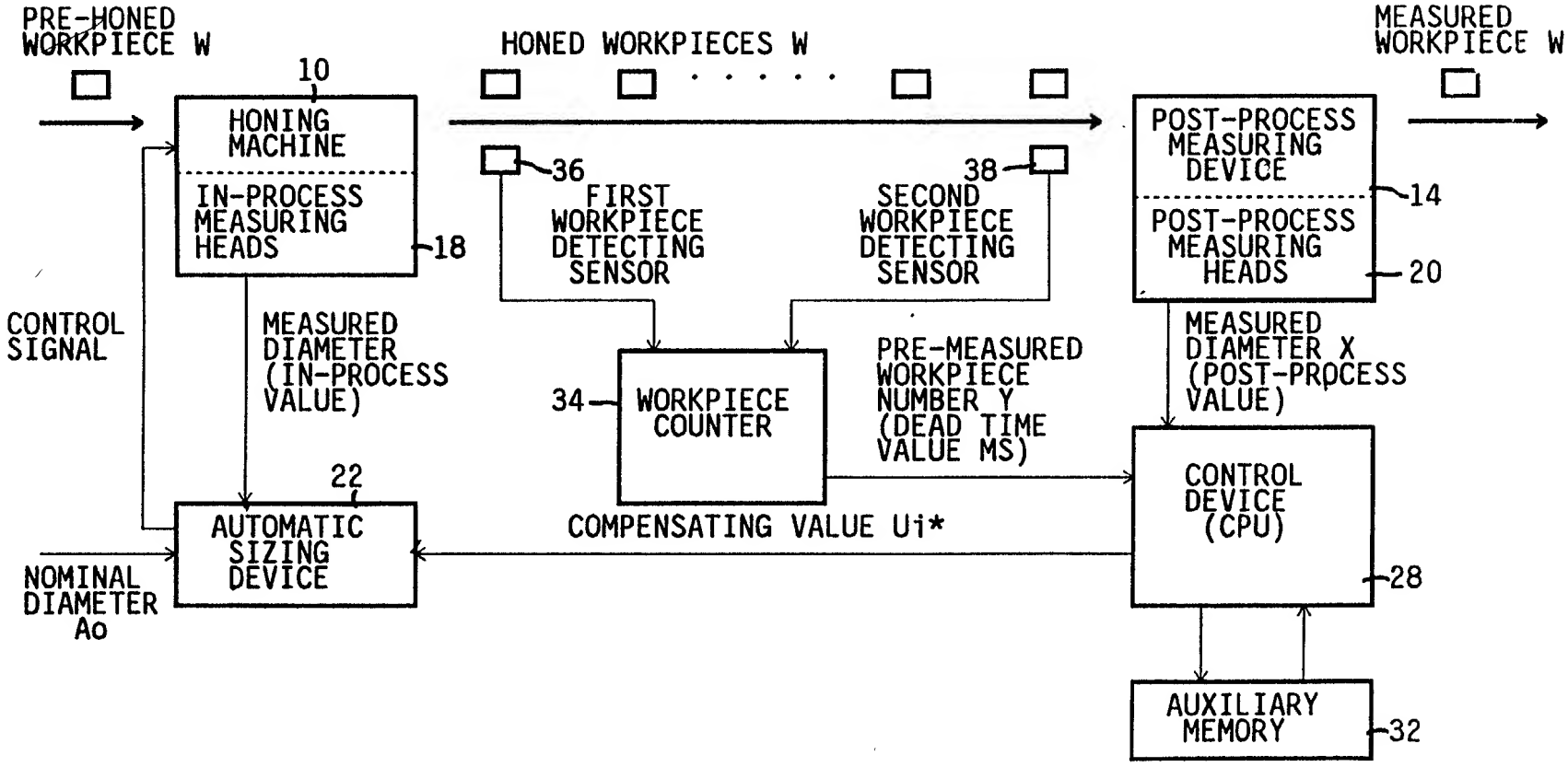


FIG. 2

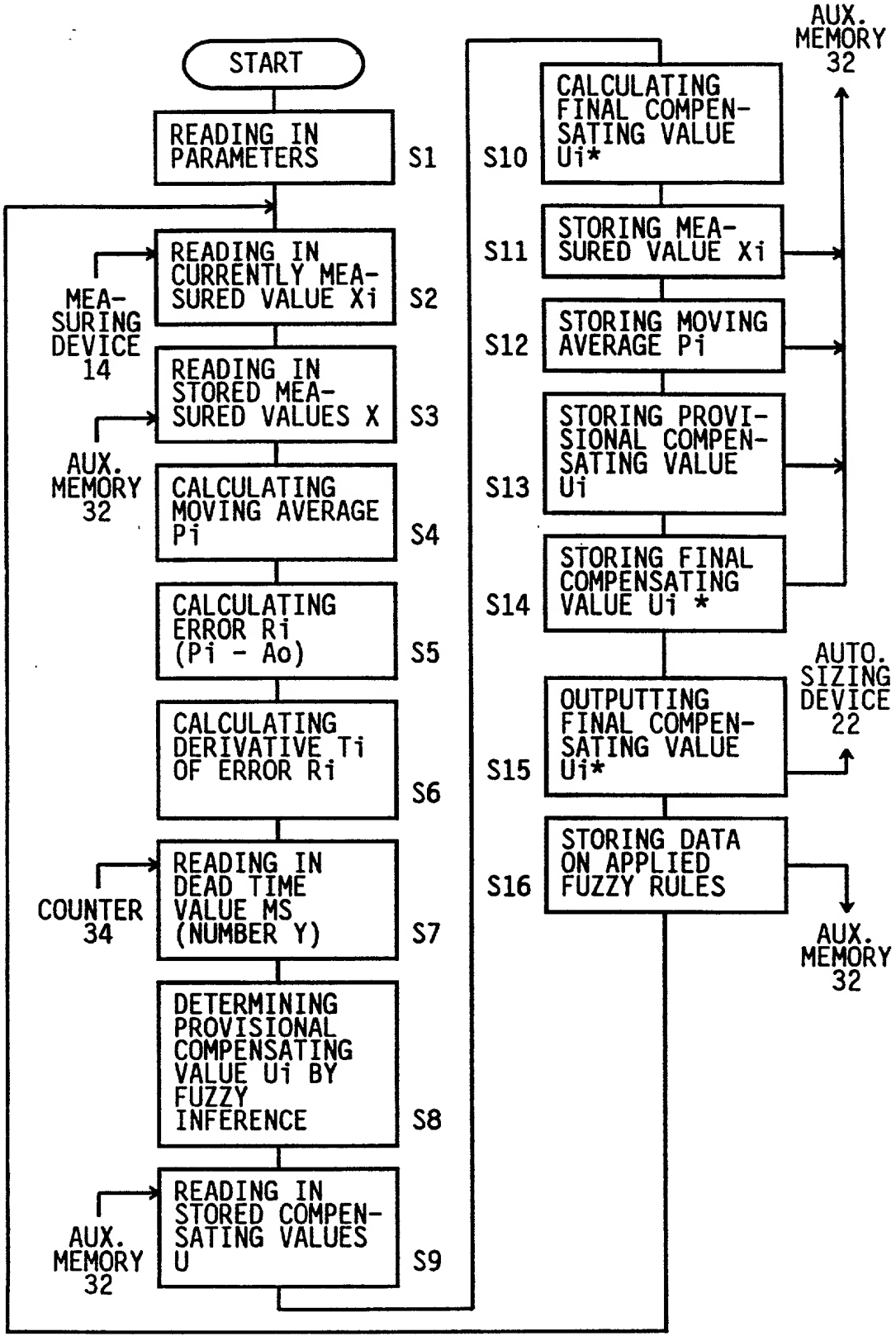

START
READING IN PARAMETERS
S1
READING IN CURRENTLY MEASURED VALUE Xi
S2
MEASURING DEVICE 14
READING IN STORED MEASURED VALUES X
S3
AUX. MEMORY 32
CALCULATING MOVING AVERAGE Pi
S4
CALCULATING ERROR Ri (Pi - Ao)
S5
CALCULATING DERIVATIVE Ti OF ERROR Ri
S6
READING IN DEAD TIME VALUE MS (NUMBER Y)
S7
COUNTER 34
DETERMINING PROVISIONAL COMPENSATING VALUE Ui BY FUZZY INFERENCE
S8
READING IN STORED COMPENSATING VALUES U
S9
AUX. MEMORY 32
CALCULATING FINAL COMPENSATING VALUE Ui*
S10
STORING MEASURED VALUE Xi
S11
STORING MOVING AVERAGE Pi
S12
STORING PROVISIONAL COMPENSATING VALUE Ui
S13
STORING FINAL COMPENSATING VALUE Ui *
S14
OUTPUTTING FINAL COMPENSATING VALUE Ui*
S15
AUTO. SIZING DEVICE 22
STORING DATA ON APPLIED FUZZY RULES
S16
AUX. MEMORY 32
AUX. MEMORY 32

FIG. 3

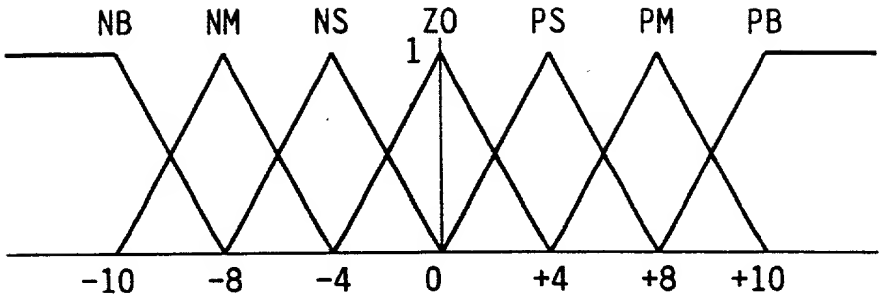


FIG. 4

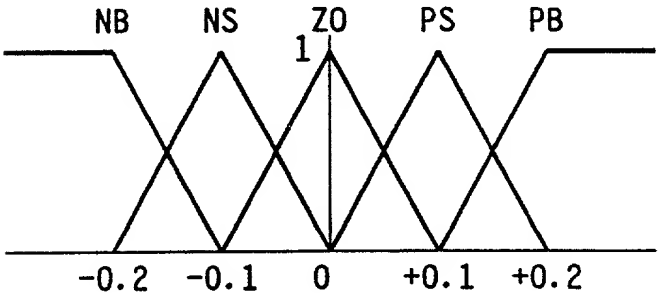


FIG. 5

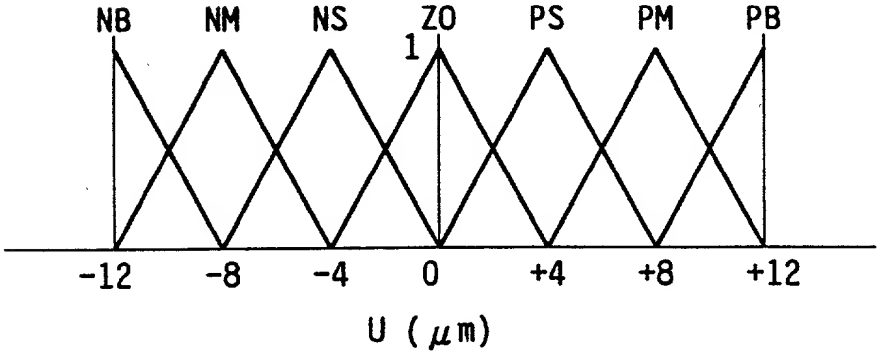


FIG. 6

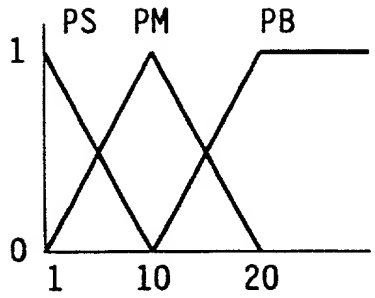


FIG. 7

DATA STORED IN AUXILIARY MEMORY 32				
MEASURED VALUES	MOVING AVERAGES	PROVI-SIONAL COMPEN-SATING VALUES	FINAL COMPEN-SATING VALUES	APPLIED FUZZY RULES
X0	P0	U0	U0*	.
X1	P1	U1	U1*	.
X2	P2	U2	U2*	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Xi	Pi	Ui	Ui*	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

FIG. 18

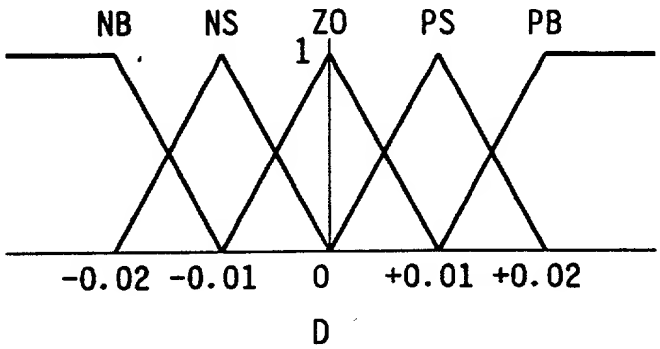


FIG. 8

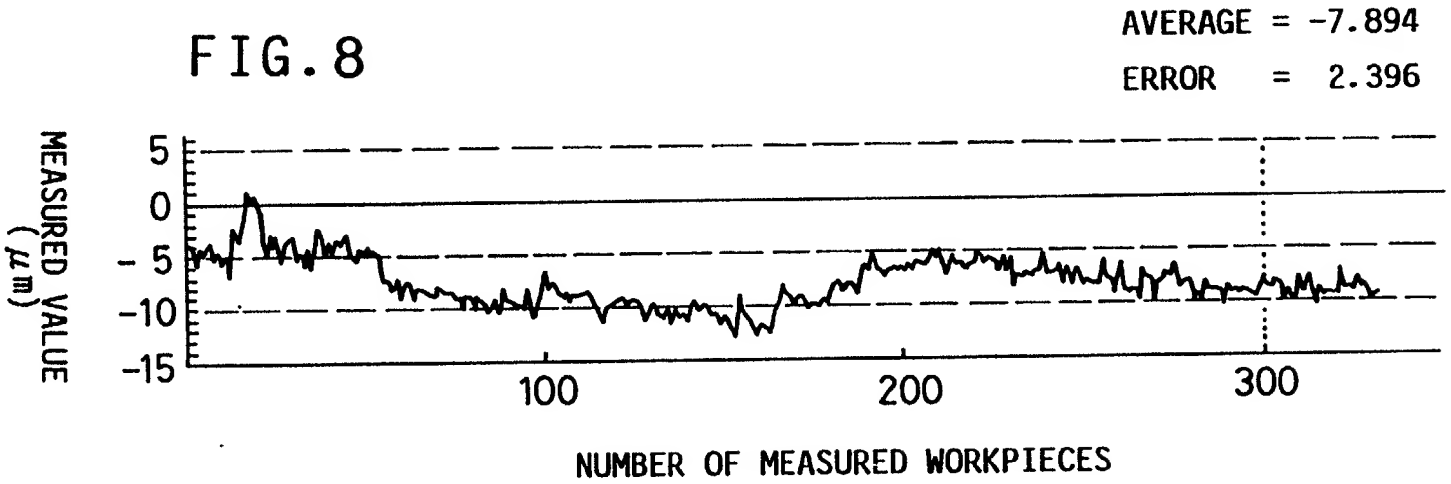

AVERAGE = -7.894
ERROR = 2.396
MEASURED VALUE (μm)
5
0
-5
-10
-15
100
200
300
NUMBER OF MEASURED WORKPIECES

FIG. 9

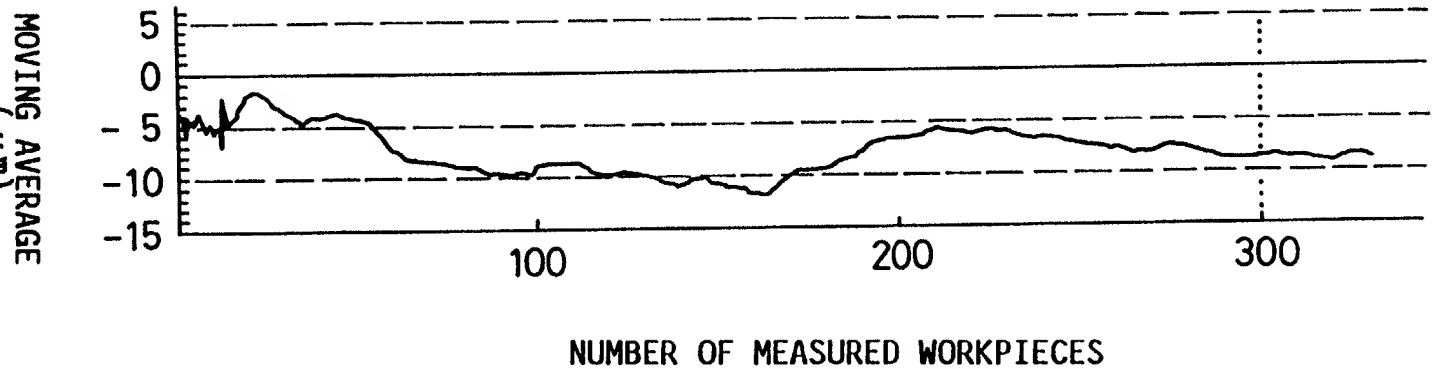

MOVING AVERAGE (μm)
5
0
-5
-10
-15
100
200
300
NUMBER OF MEASURED WORKPIECES

FIG. 10

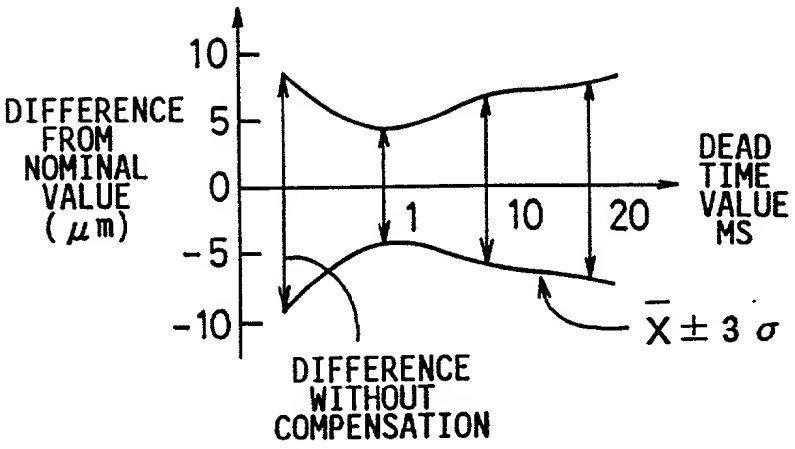

10
5
0
-5
-10
DIFFERENCE FROM NOMINAL VALUE (μm)
1
10
20
DEAD TIME VALUE MS
$\bar{X} \pm 3\sigma$
DIFFERENCE WITHOUT COMPENSATION

FIG. 11

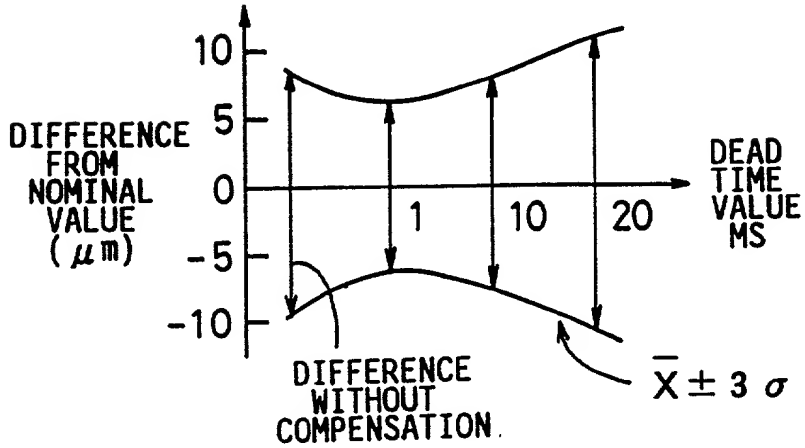

10
5
0
-5
-10
DIFFERENCE FROM NOMINAL VALUE (μm)
1
10
20
DEAD TIME VALUE MS
$\bar{X} \pm 3\sigma$
DIFFERENCE WITHOUT COMPENSATION

FIG. 12

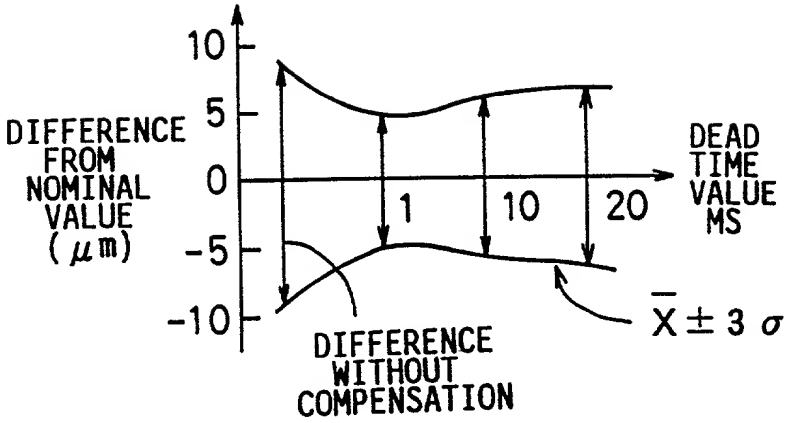

10
5
0
-5
-10
DIFFERENCE FROM NOMINAL VALUE (μm)
1
10
20
DEAD TIME VALUE MS
$\bar{X} \pm 3\sigma$
DIFFERENCE WITHOUT COMPENSATION

FIG. 13

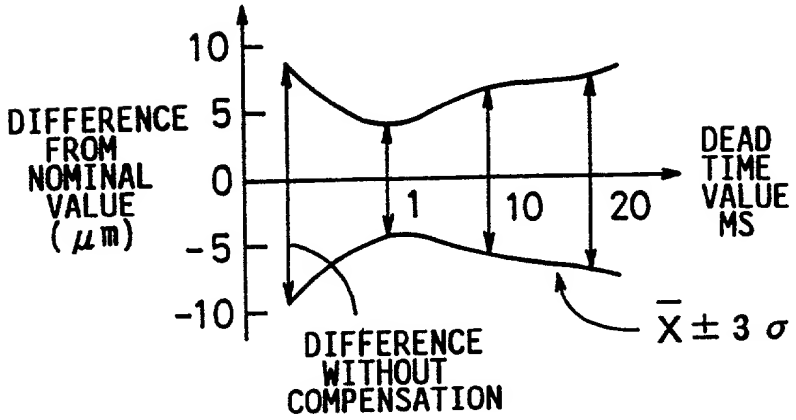

10
5
0
-5
-10
DIFFERENCE FROM NOMINAL VALUE (μm)
1
10
20
DEAD TIME VALUE MS
$\bar{X} \pm 3\sigma$
DIFFERENCE WITHOUT COMPENSATION

FIG. 14

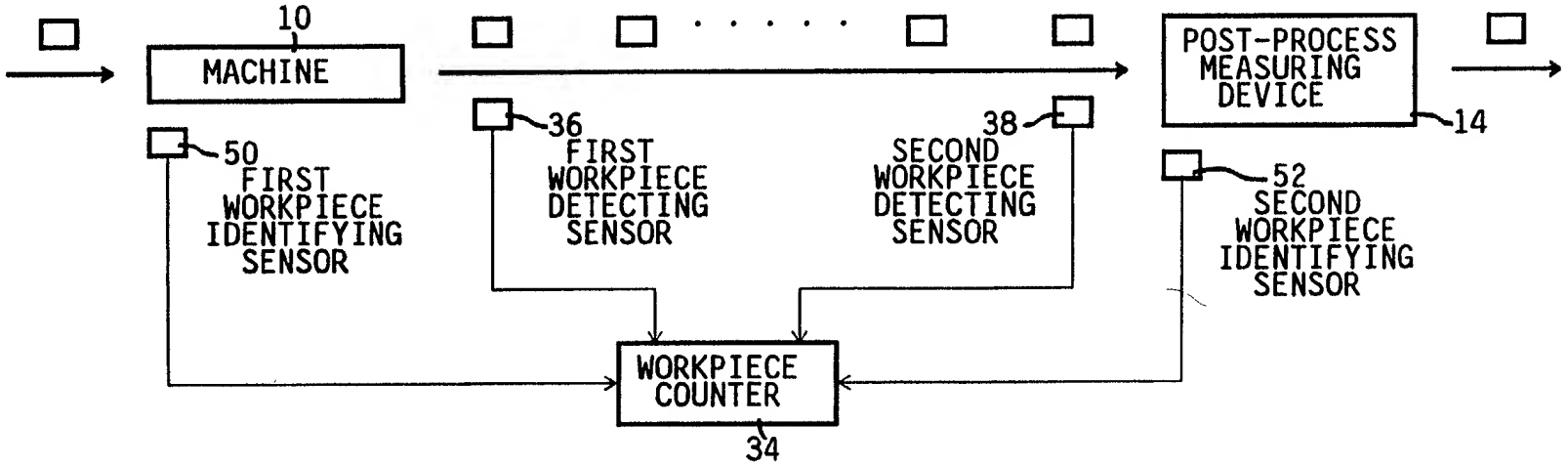

10
MACHINE
50
FIRST WORKPIECE IDENTIFYING SENSOR
36
FIRST WORKPIECE DETECTING SENSOR
38
SECOND WORKPIECE DETECTING SENSOR
POST-PROCESS MEASURING DEVICE
14
52
SECOND WORKPIECE IDENTIFYING SENSOR
WORKPIECE COUNTER
34

FIG. 15

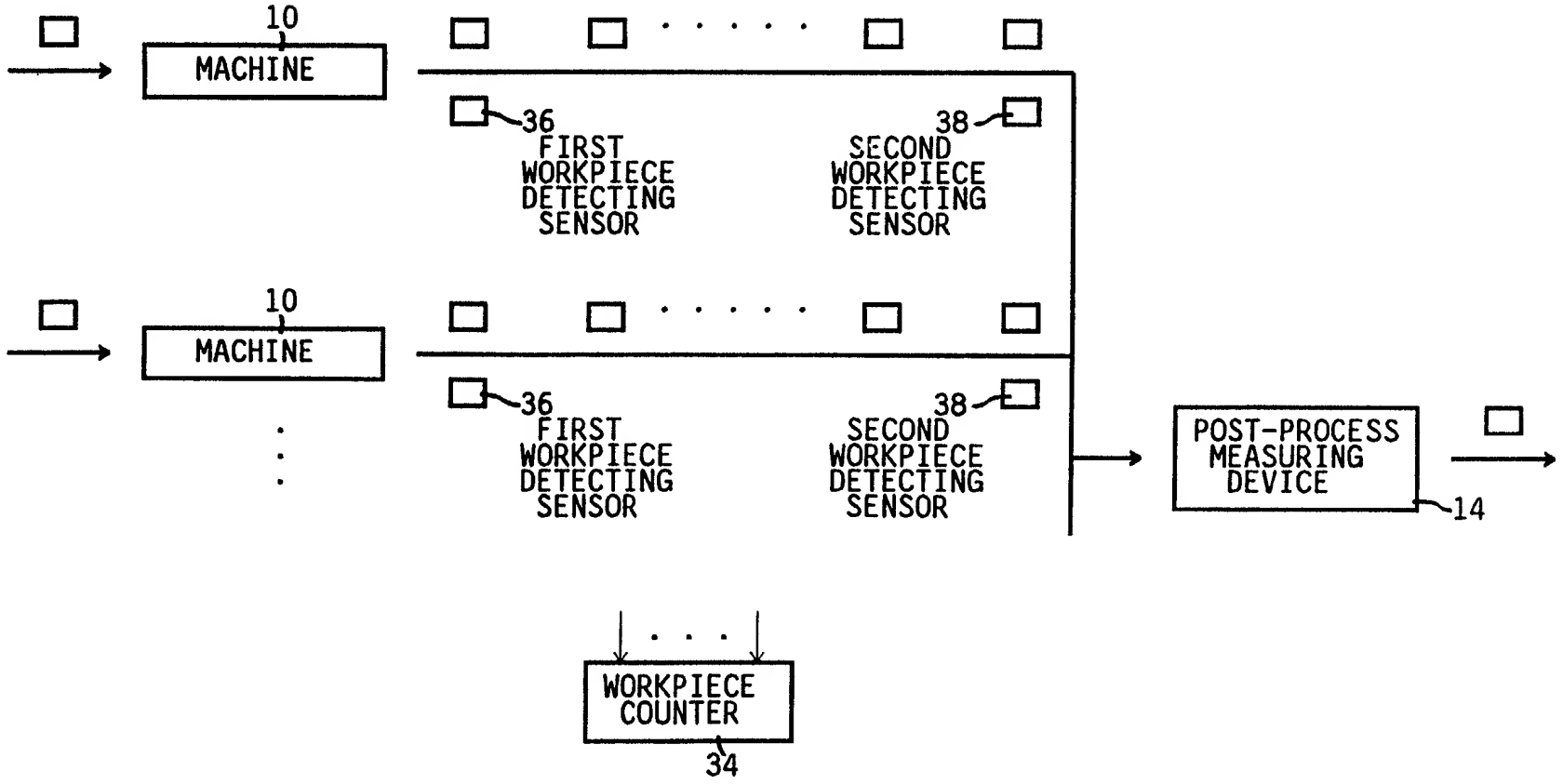

10
MACHINE
36
FIRST WORKPIECE DETECTING SENSOR
38
SECOND WORKPIECE DETECTING SENSOR
10
MACHINE
36
FIRST WORKPIECE DETECTING SENSOR
38
SECOND WORKPIECE DETECTING SENSOR
POST-PROCESS MEASURING DEVICE
14
WORKPIECE COUNTER
34

FIG. 16

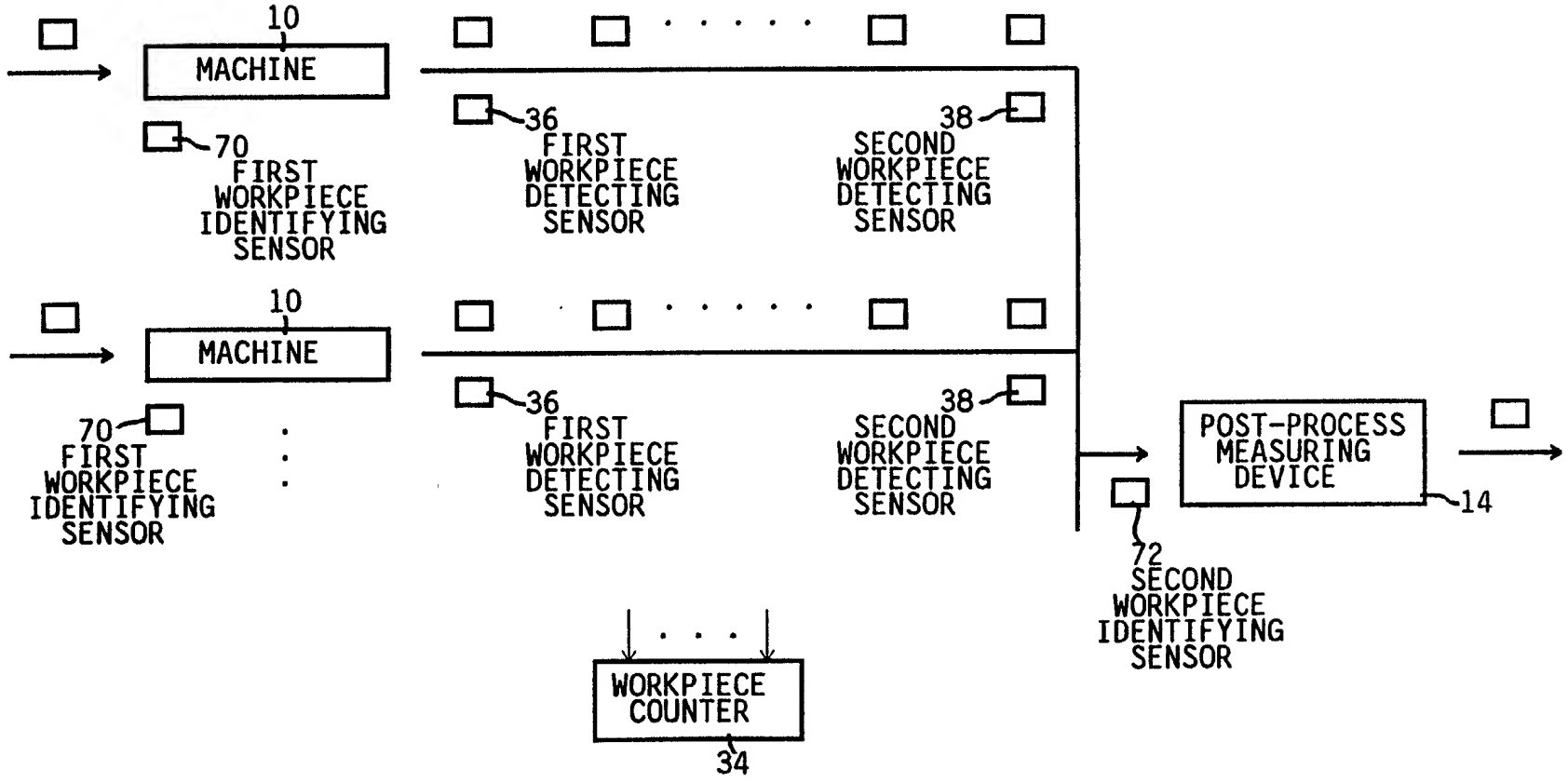

10
MACHINE
70
FIRST WORKPIECE IDENTIFYING SENSOR
36
FIRST WORKPIECE DETECTING SENSOR
38
SECOND WORKPIECE DETECTING SENSOR
10
MACHINE
70
FIRST WORKPIECE IDENTIFYING SENSOR
36
FIRST WORKPIECE DETECTING SENSOR
38
SECOND WORKPIECE DETECTING SENSOR
POST-PROCESS MEASURING DEVICE
14
72
SECOND WORKPIECE IDENTIFYING SENSOR
WORKPIECE COUNTER
34

FIG. 17

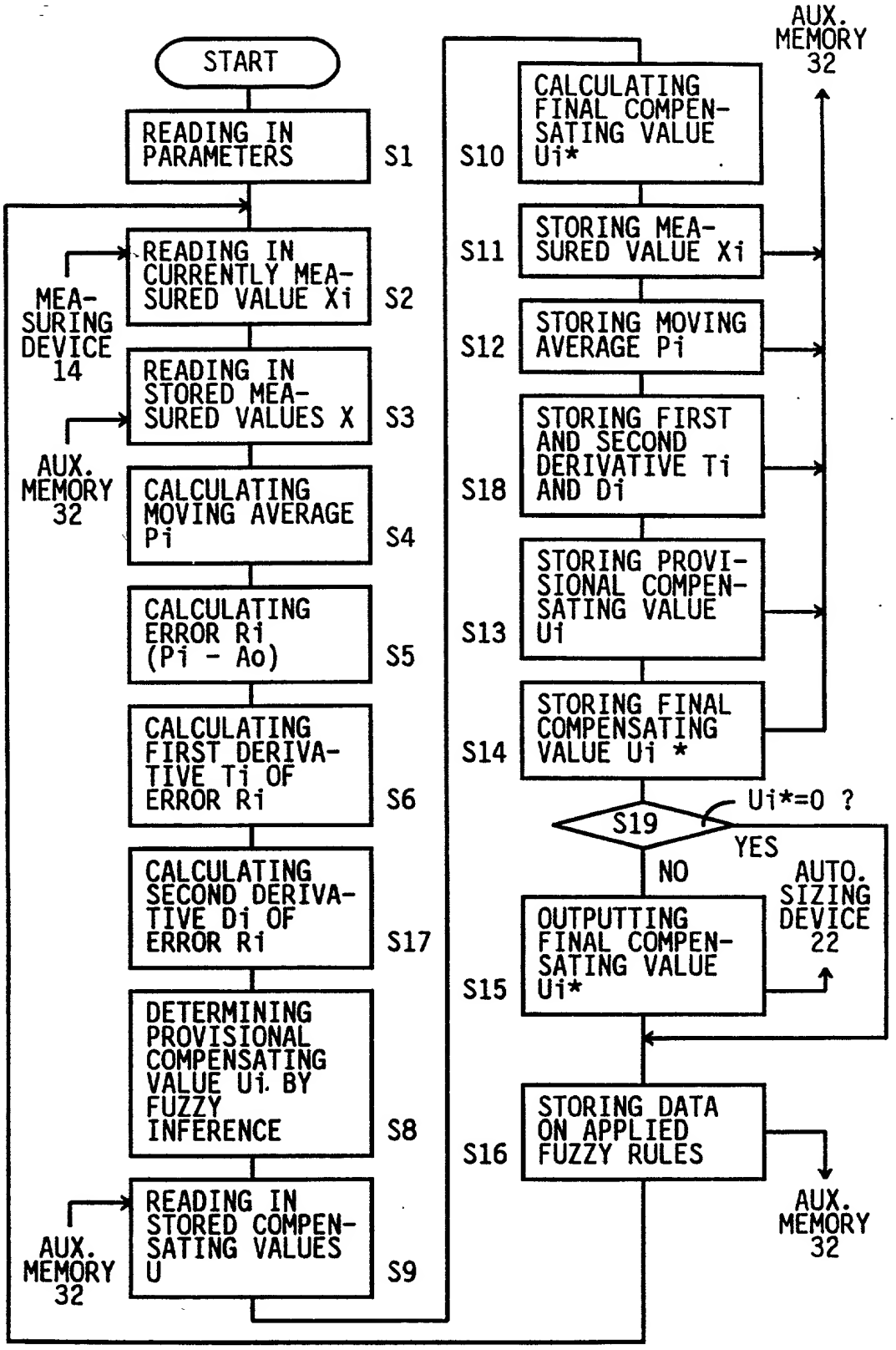

START
READING IN PARAMETERS
S1
READING IN CURRENTLY MEASURED VALUE Xi
S2
MEASURING DEVICE 14
READING IN STORED MEASURED VALUES X
S3
AUX. MEMORY 32
CALCULATING MOVING AVERAGE Pi
S4
CALCULATING ERROR Ri (Pi - Ao)
S5
CALCULATING FIRST DERIVATIVE Ti OF ERROR Ri
S6
CALCULATING SECOND DERIVATIVE Di OF ERROR Ri
S17
DETERMINING PROVISIONAL COMPENSATING VALUE Ui BY FUZZY INFERENCE
S8
READING IN STORED COMPENSATING VALUES U
S9
AUX. MEMORY 32
CALCULATING FINAL COMPENSATING VALUE Ui*
S10
STORING MEASURED VALUE Xi
S11
STORING MOVING AVERAGE Pi
S12
STORING FIRST AND SECOND DERIVATIVE Ti AND Di
S18
STORING PROVISIONAL COMPENSATING VALUE Ui
S13
STORING FINAL COMPENSATING VALUE Ui *
S14
AUX. MEMORY 32
Ui*=0 ?
S19
YES
NO
OUTPUTTING FINAL COMPENSATING VALUE Ui*
S15
AUTO. SIZING DEVICE 22
STORING DATA ON APPLIED FUZZY RULES
S16
AUX. MEMORY 32

FIG. 19

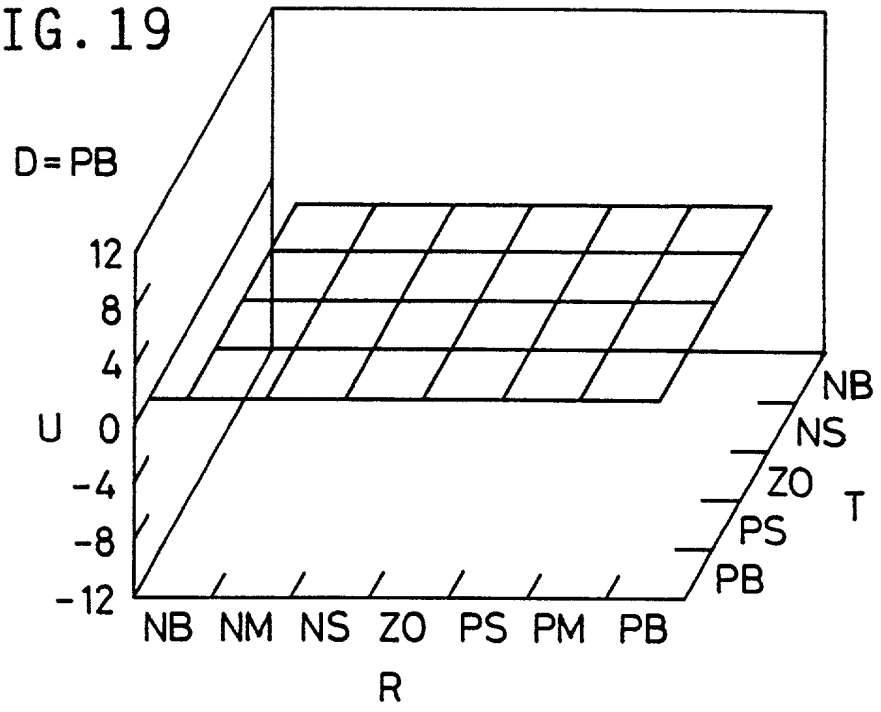

D=PB
12
8
4
U 0
-4
-8
-12
NB NM NS ZO PS PM PB
R
NB
NS
ZO
PS
PB
T

FIG. 20

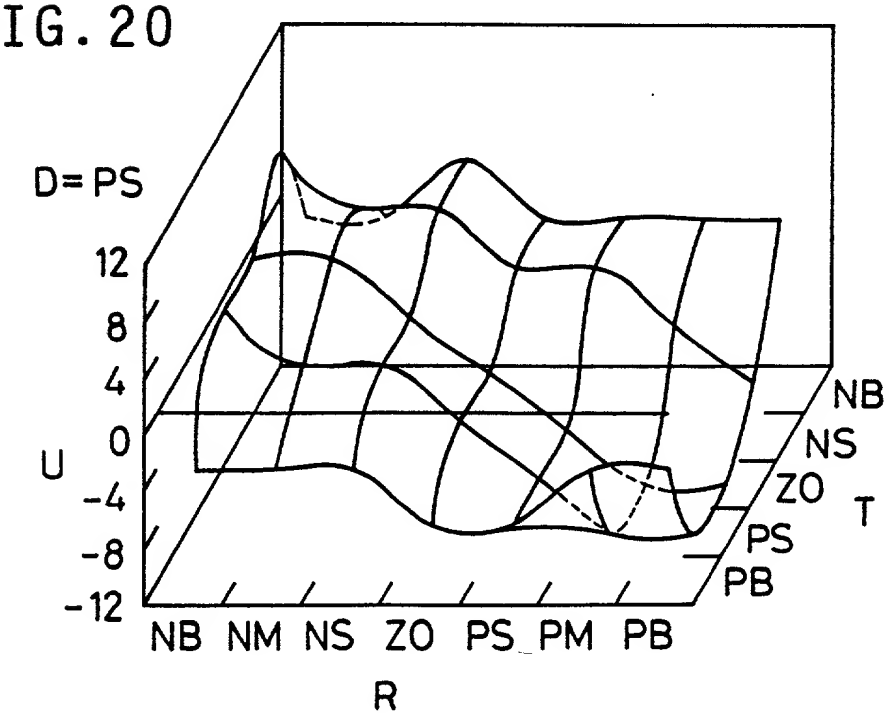

D=PS
12
8
4
U 0
-4
-8
-12
NB NM NS ZO PS PM PB
R
NB
NS
ZO
PS
PB
T

FIG. 21

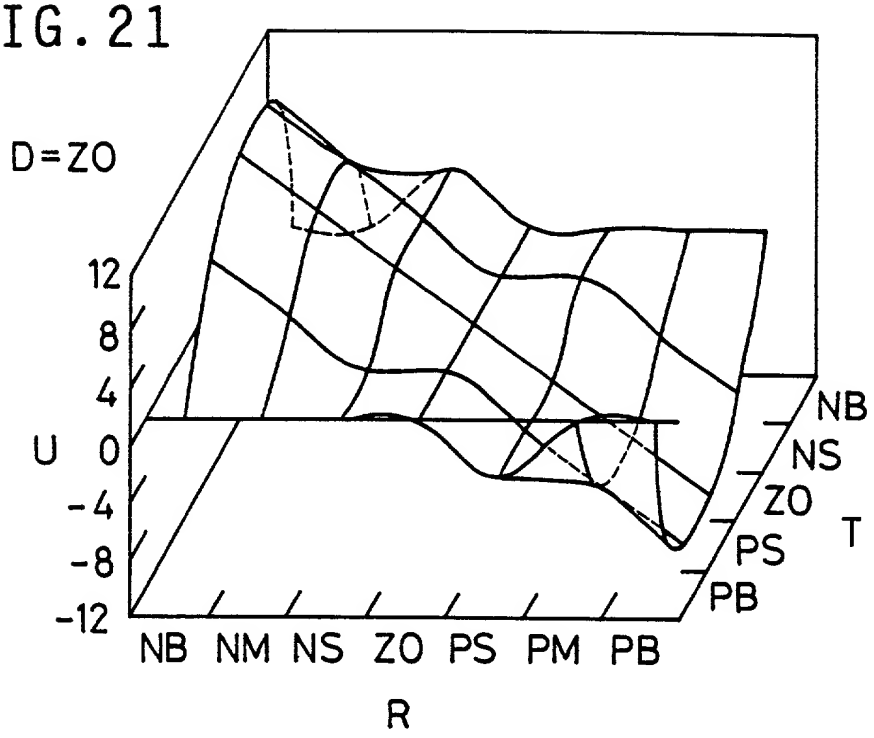

D=ZO
12
8
4
U 0
-4
-8
-12
NB NM NS ZO PS PM PB
R
NB
NS
ZO
PS
PB
T

FIG. 22

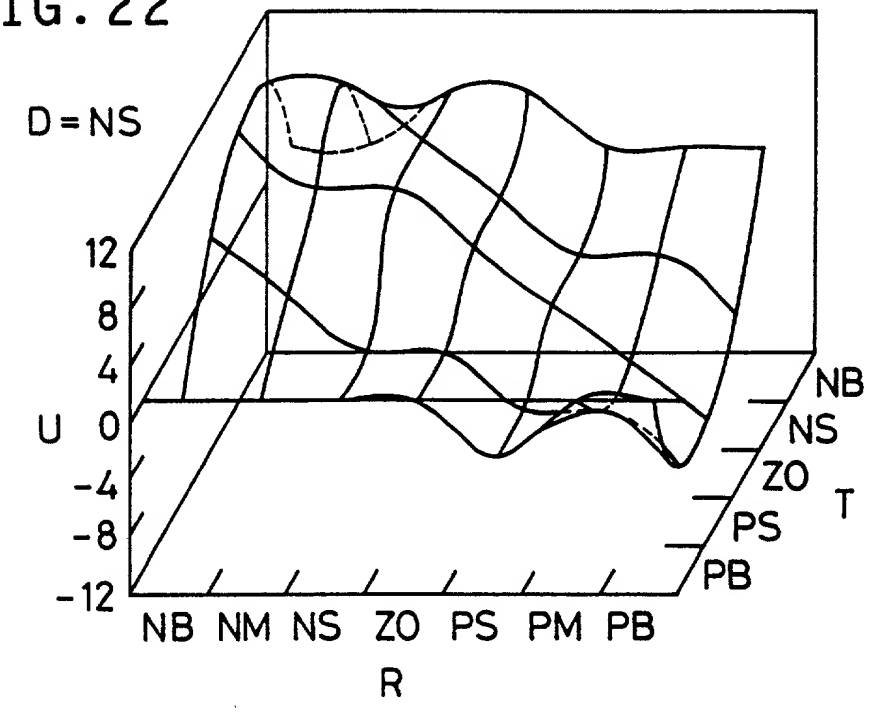

D=NS
12
8
4
U 0
-4
-8
-12
NB NM NS ZO PS PM PB
R
NB
NS
ZO
PS
PB
T

FIG. 23

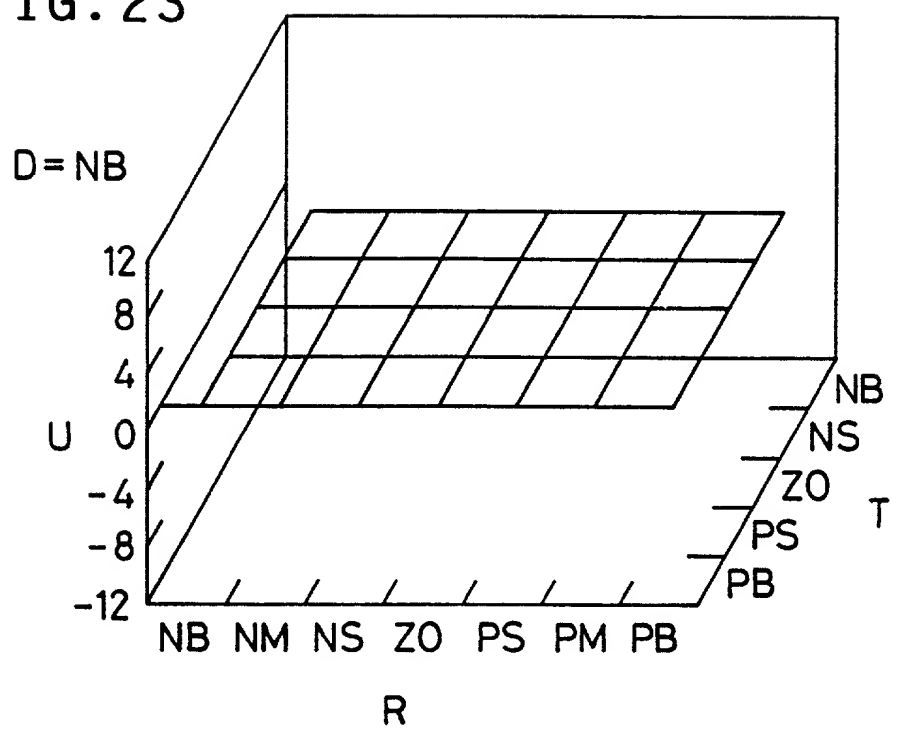


FIG. 24

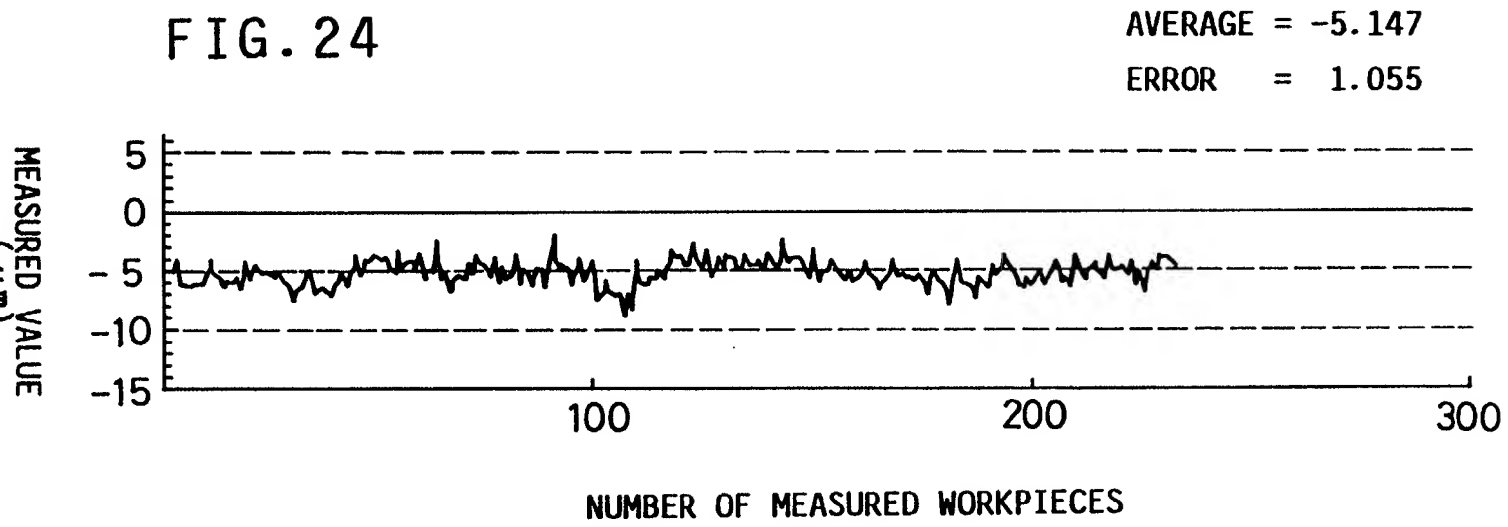


FIG. 25

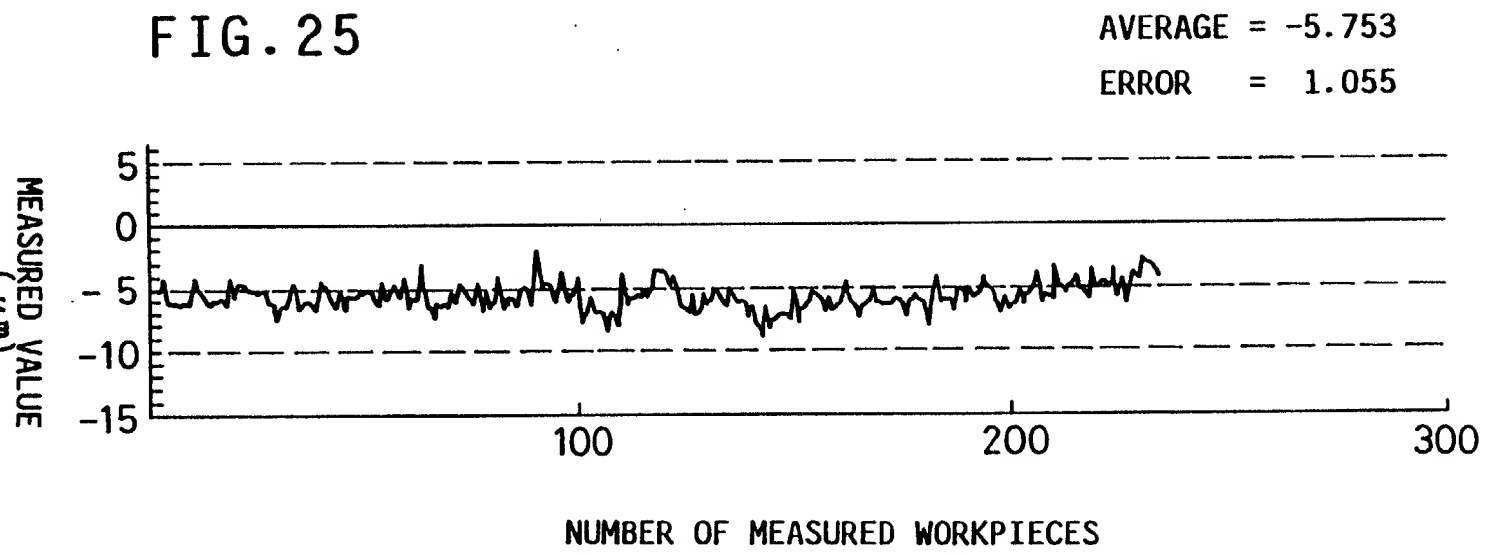

AVERAGE = -5.753
ERROR = 1.055
MEASURED VALUE (μm)
5
0
- 5
-10
-15
100
200
300
NUMBER OF MEASURED WORKPIECES

FIG. 26

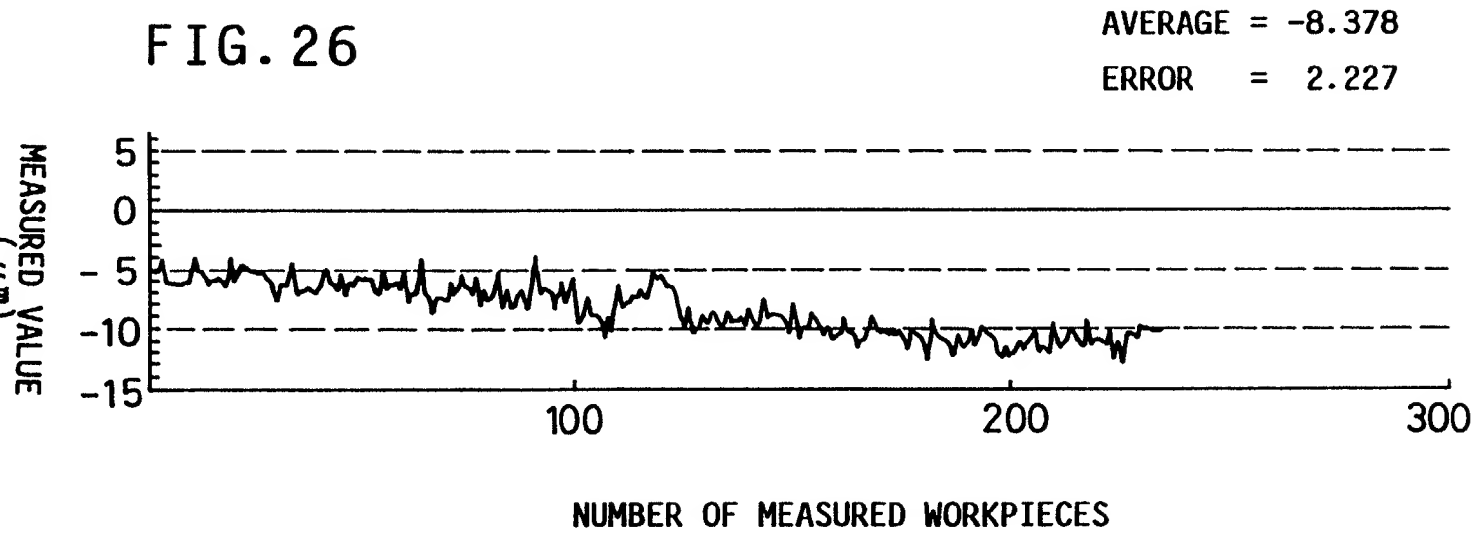
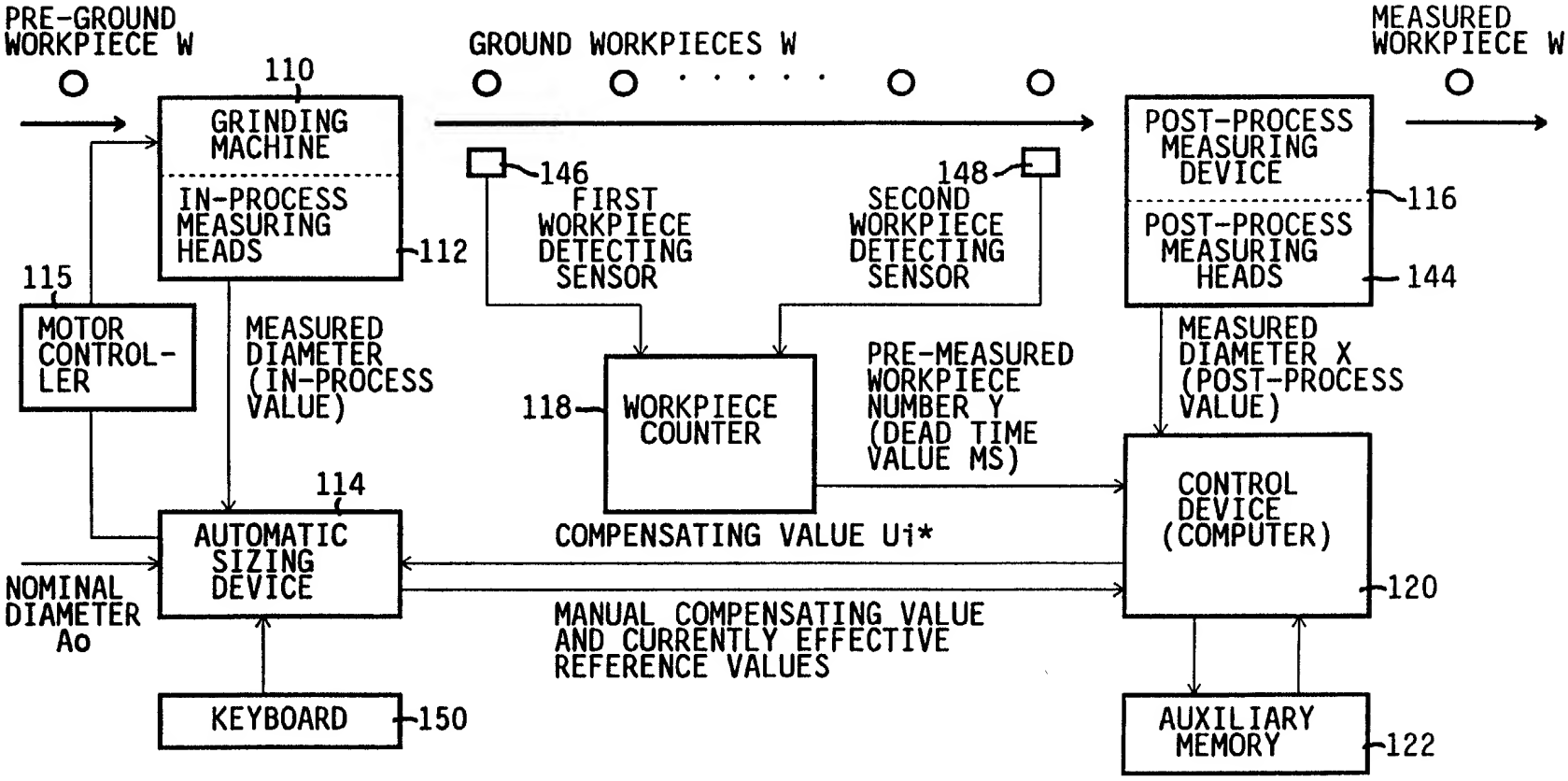


FIG. 27


PRE-GROUND WORKPIECE W
GROUND WORKPIECES W
MEASURED WORKPIECE W
110
GRINDING MACHINE
IN-PROCESS MEASURING HEADS
112
115
MOTOR CONTROL-LER
MEASURED DIAMETER (IN-PROCESS VALUE)
146
FIRST WORKPIECE DETECTING SENSOR
148
SECOND WORKPIECE DETECTING SENSOR
POST-PROCESS MEASURING DEVICE
116
POST-PROCESS MEASURING HEADS
144
MEASURED DIAMETER X (POST-PROCESS VALUE)
118
WORKPIECE COUNTER
PRE-MEASURED WORKPIECE NUMBER Y (DEAD TIME VALUE MS)
114
AUTOMATIC SIZING DEVICE
COMPENSATING VALUE Ui*
CONTROL DEVICE (COMPUTER)
120
NOMINAL DIAMETER Ao
MANUAL COMPENSATING VALUE AND CURRENTLY EFFECTIVE REFERENCE VALUES
KEYBOARD
150
AUXILIARY MEMORY
122

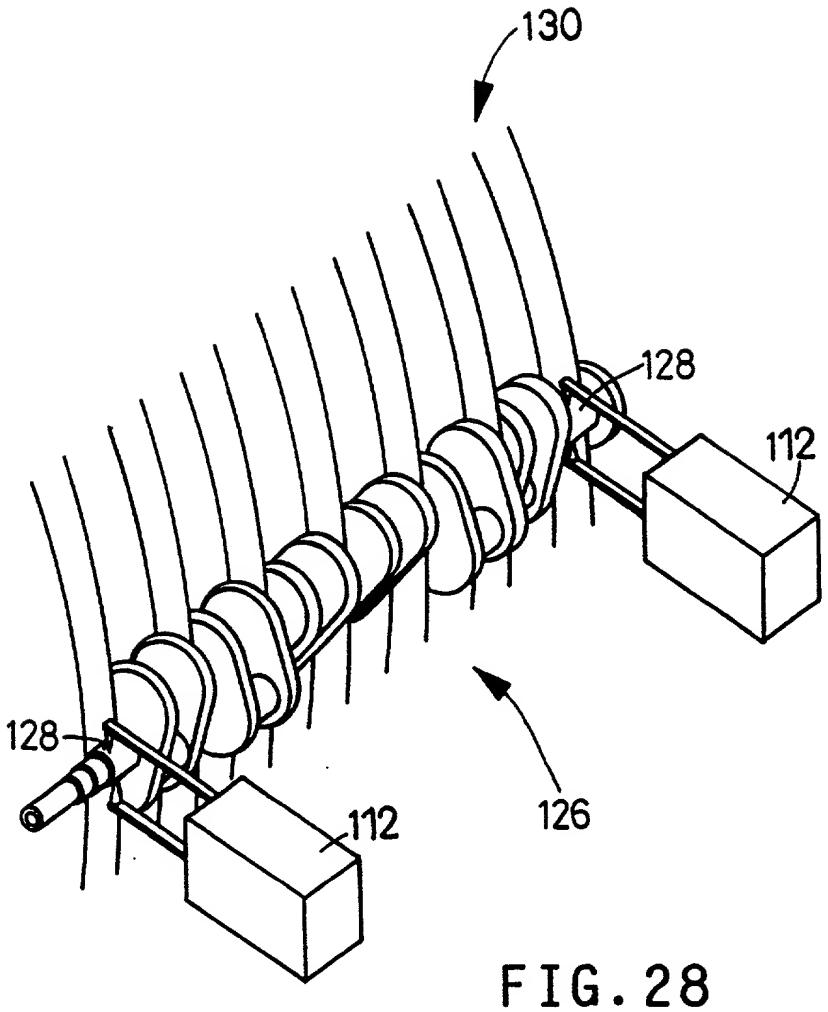


FIG. 28

FIG. 29

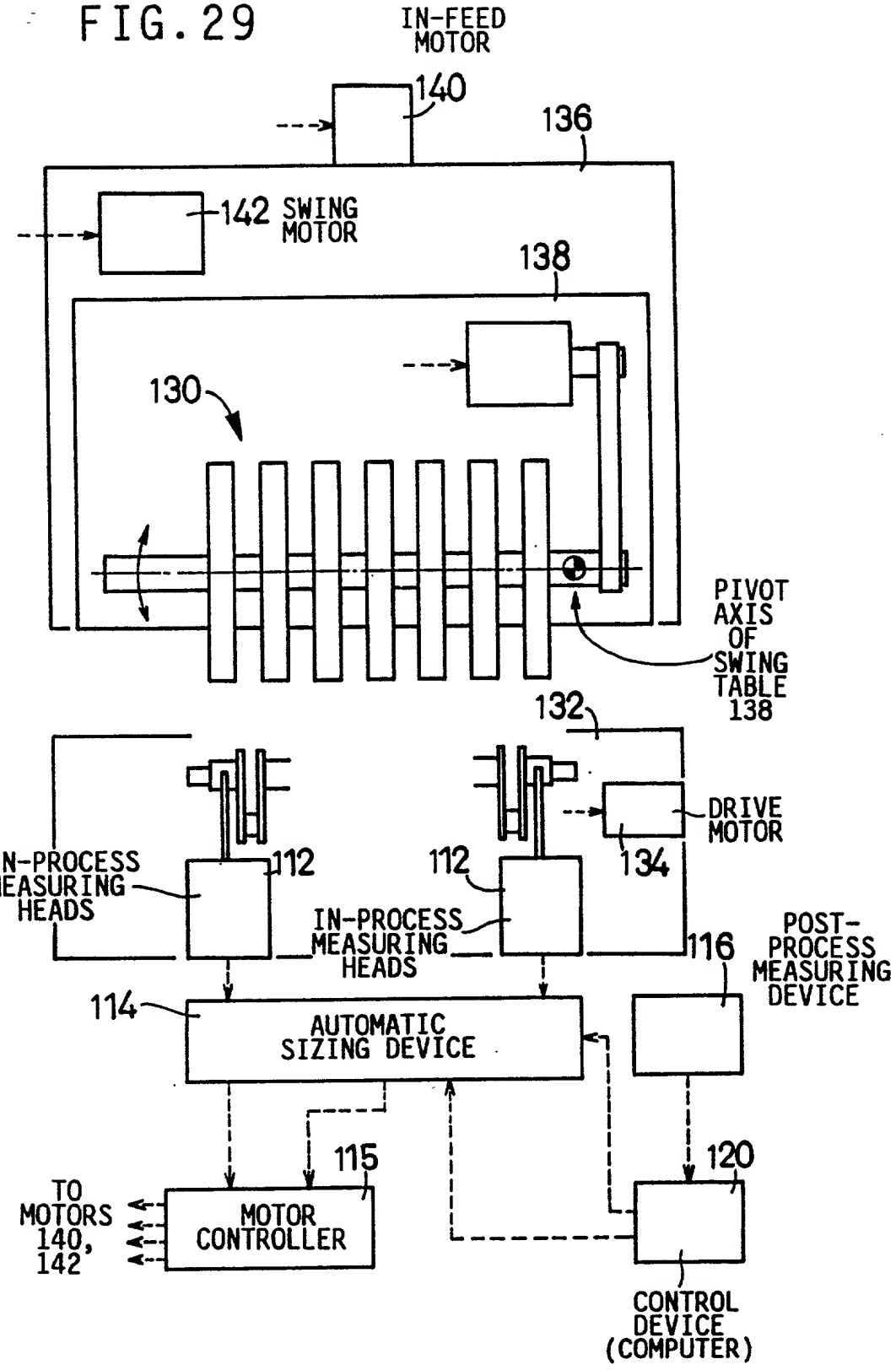

IN-FEED MOTOR
140
136
142 SWING MOTOR
138
130
PIVOT AXIS OF SWING TABLE 138
132
DRIVE MOTOR
134
IN-PROCESS MEASURING HEADS
112
112
IN-PROCESS MEASURING HEADS
116
POST-PROCESS MEASURING DEVICE
114
AUTOMATIC SIZING DEVICE
115
120
TO MOTORS 140, 142
MOTOR CONTROLLER
CONTROL DEVICE (COMPUTER)

FIG. 30A

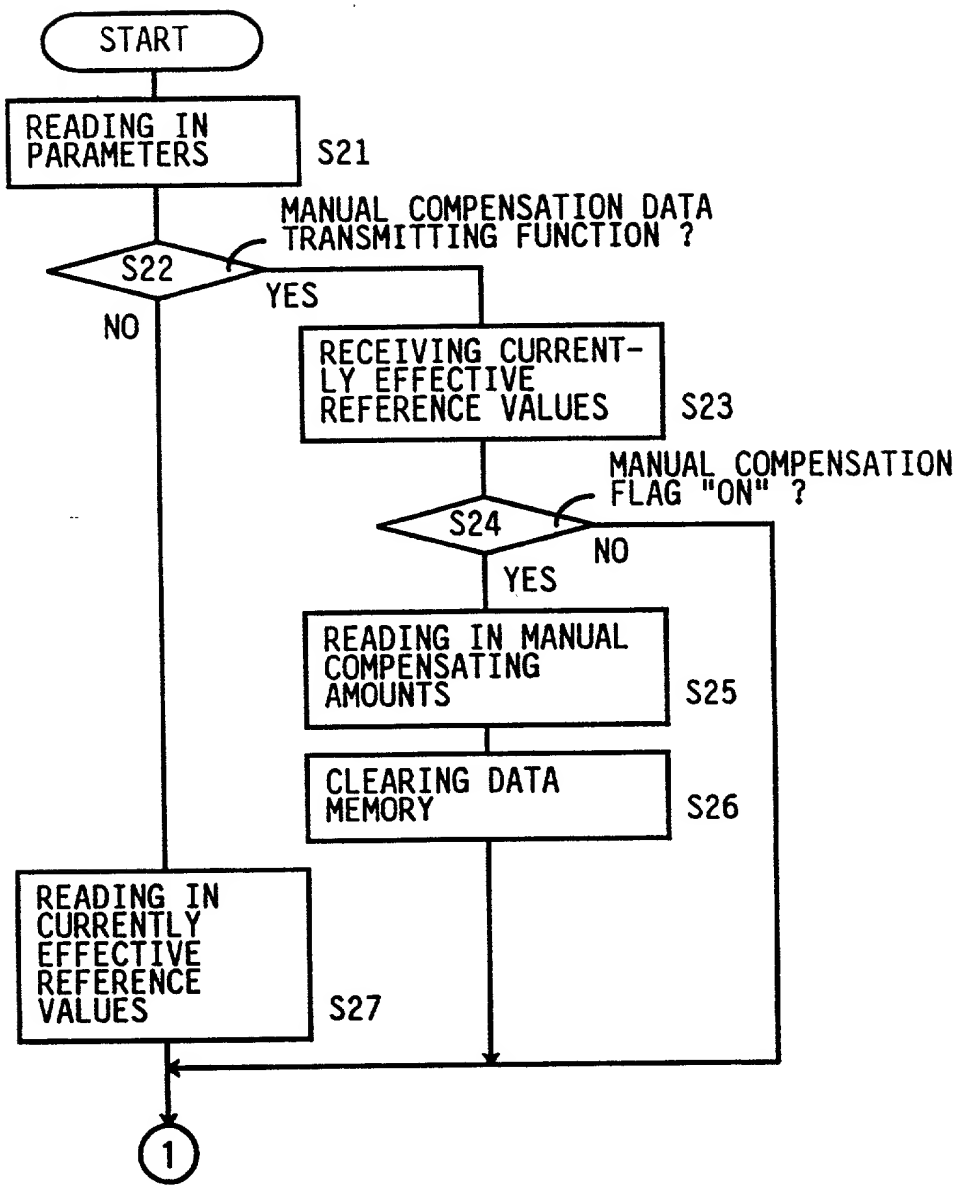

START
READING IN PARAMETERS
S21
MANUAL COMPENSATION DATA TRANSMITTING FUNCTION ?
S22
YES
NO
RECEIVING CURRENTLY EFFECTIVE REFERENCE VALUES
S23
MANUAL COMPENSATION FLAG "ON" ?
S24
NO
YES
READING IN MANUAL COMPENSATING AMOUNTS
S25
CLEARING DATA MEMORY
S26
READING IN CURRENTLY EFFECTIVE REFERENCE VALUES
S27
1

FIG. 30B

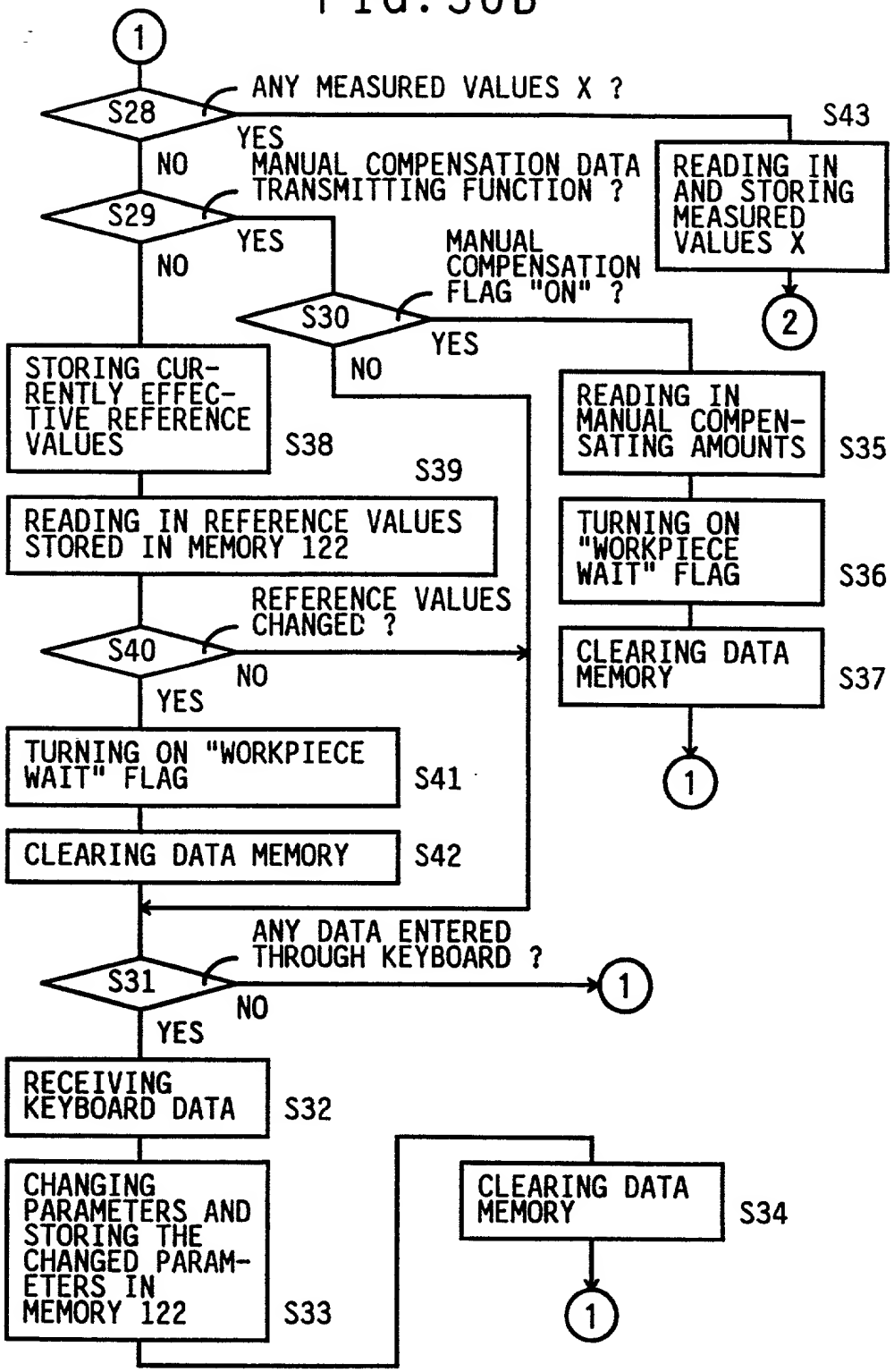

1
S28
ANY MEASURED VALUES X ?
YES
NO
S43
READING IN AND STORING MEASURED VALUES X
2
S29
MANUAL COMPENSATION DATA TRANSMITTING FUNCTION ?
YES
NO
S30
MANUAL COMPENSATION FLAG "ON" ?
YES
NO
STORING CURRENTLY EFFECTIVE REFERENCE VALUES
S38
READING IN MANUAL COMPENSATING AMOUNTS
S35
S39
READING IN REFERENCE VALUES STORED IN MEMORY 122
TURNING ON "WORKPIECE WAIT" FLAG
S36
S40
REFERENCE VALUES CHANGED ?
NO
YES
CLEARING DATA MEMORY
S37
1
TURNING ON "WORKPIECE WAIT" FLAG
S41
CLEARING DATA MEMORY
S42
S31
ANY DATA ENTERED THROUGH KEYBOARD ?
NO
YES
1
RECEIVING KEYBOARD DATA
S32
CHANGING PARAMETERS AND STORING THE CHANGED PARAMETERS IN MEMORY 122
S33
CLEARING DATA MEMORY
S34
1

FIG. 31A

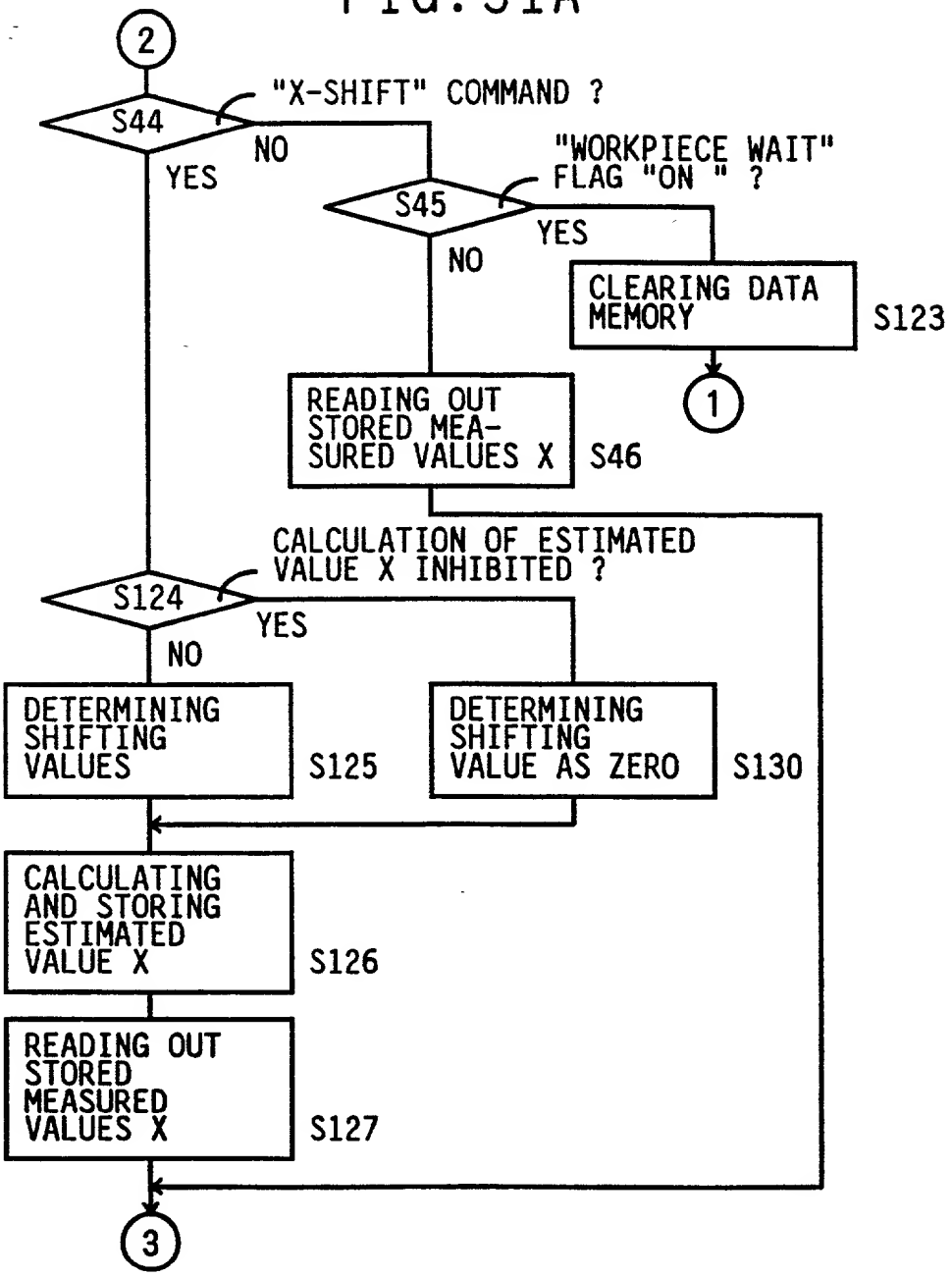

2
S44
"X-SHIFT" COMMAND ?
NO
YES
S45
"WORKPIECE WAIT" FLAG "ON " ?
YES
NO
CLEARING DATA MEMORY
S123
1
READING OUT STORED MEA-SURED VALUES X
S46
S124
CALCULATION OF ESTIMATED VALUE X INHIBITED ?
YES
NO
DETERMINING SHIFTING VALUES
S125
DETERMINING SHIFTING VALUE AS ZERO
S130
CALCULATING AND STORING ESTIMATED VALUE X
S126
READING OUT STORED MEASURED VALUES X
S127
3

FIG. 31B

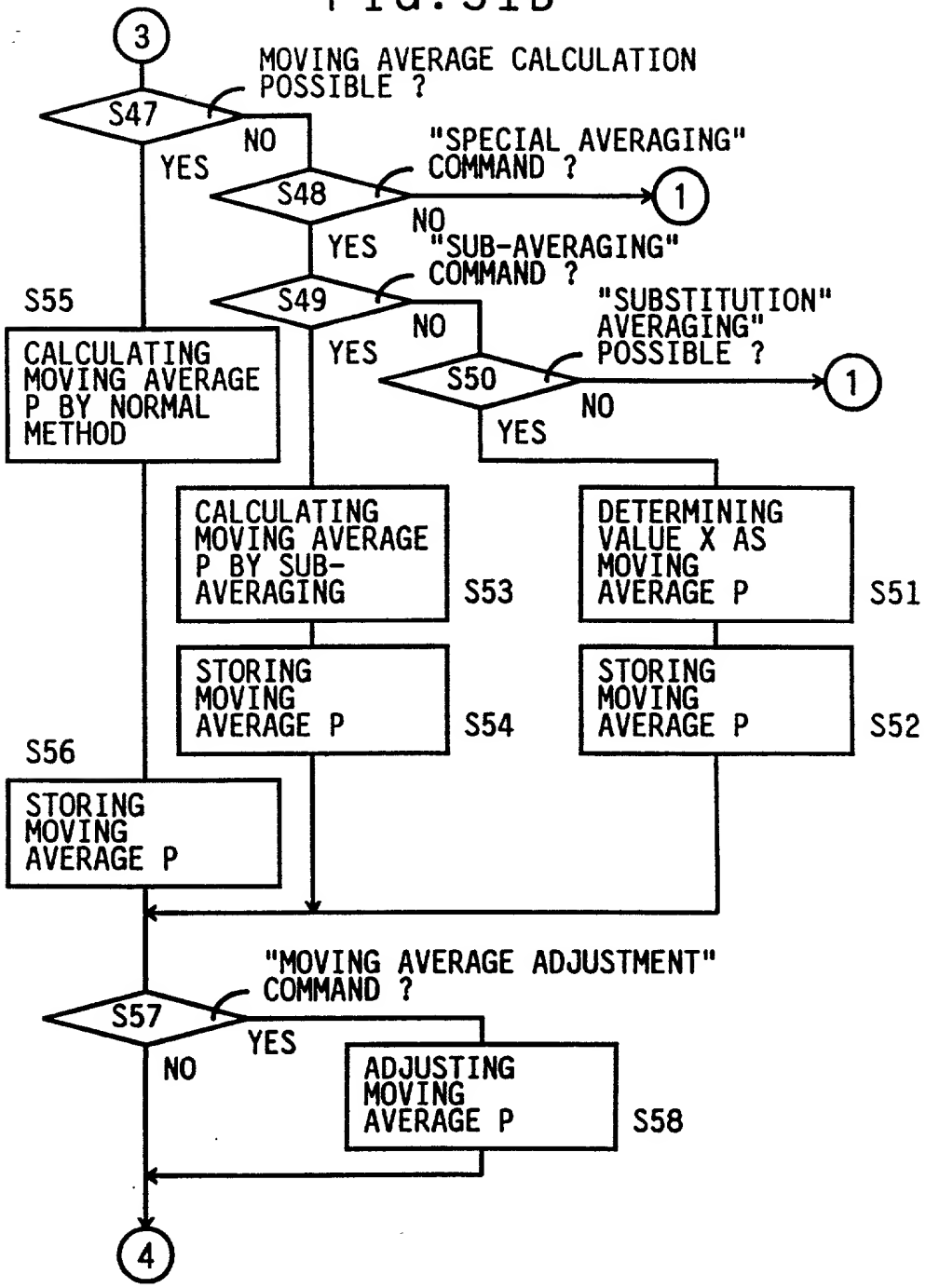

3
MOVING AVERAGE CALCULATION POSSIBLE ?
S47
NO
YES
"SPECIAL AVERAGING" COMMAND ?
S48
1
NO
YES
"SUB-AVERAGING" COMMAND ?
S49
NO
YES
"SUBSTITUTION" AVERAGING" POSSIBLE ?
S50
1
NO
YES
S55
CALCULATING MOVING AVERAGE P BY NORMAL METHOD
CALCULATING MOVING AVERAGE P BY SUB-AVERAGING
S53
DETERMINING VALUE X AS MOVING AVERAGE P
S51
STORING MOVING AVERAGE P
S54
STORING MOVING AVERAGE P
S52
S56
STORING MOVING AVERAGE P
"MOVING AVERAGE ADJUSTMENT" COMMAND ?
S57
YES
NO
ADJUSTING MOVING AVERAGE P
S58
4

FIG. 32A

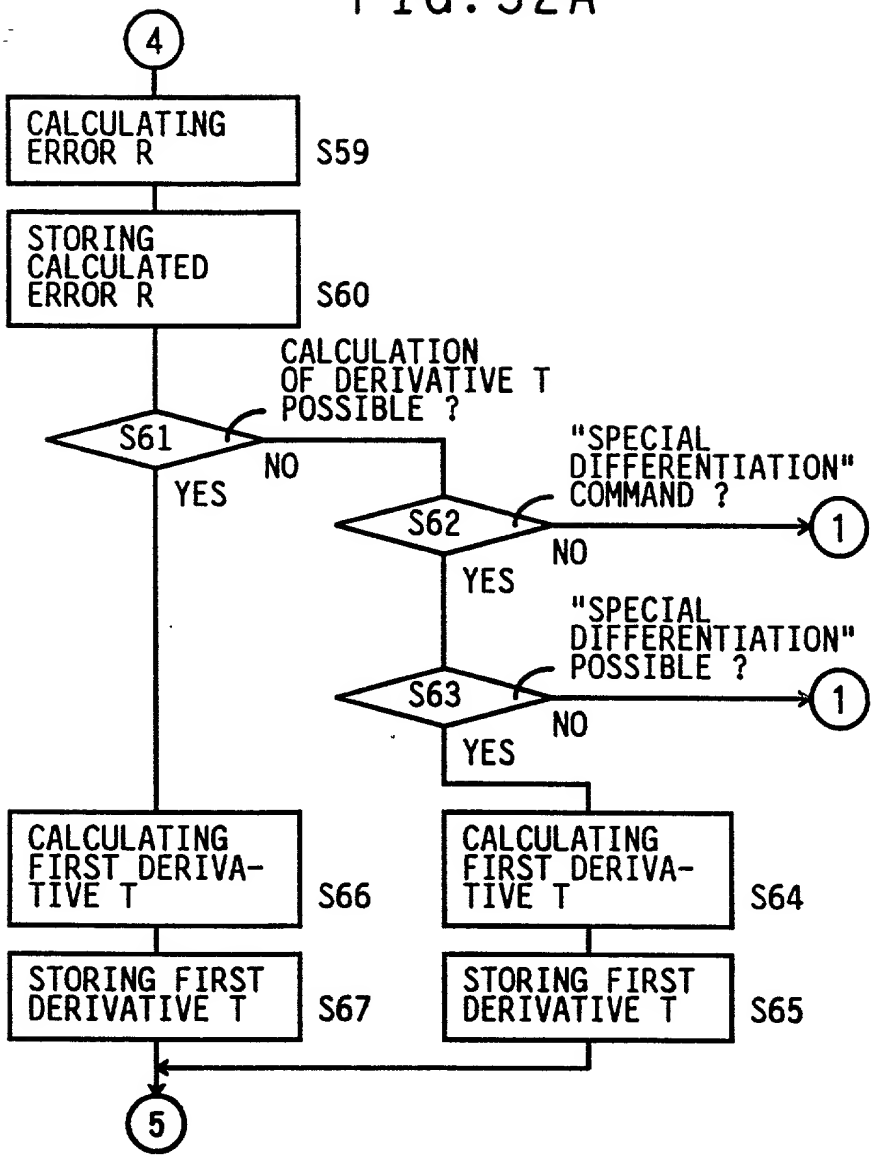

4
CALCULATING ERROR R
S59
STORING CALCULATED ERROR R
S60
CALCULATION OF DERIVATIVE T POSSIBLE ?
S61
NO
YES
"SPECIAL DIFFERENTIATION" COMMAND ?
S62
NO
YES
1
"SPECIAL DIFFERENTIATION" POSSIBLE ?
S63
NO
YES
1
CALCULATING FIRST DERIVATIVE T
S66
STORING FIRST DERIVATIVE T
S67
CALCULATING FIRST DERIVATIVE T
S64
STORING FIRST DERIVATIVE T
S65
5

FIG. 32B

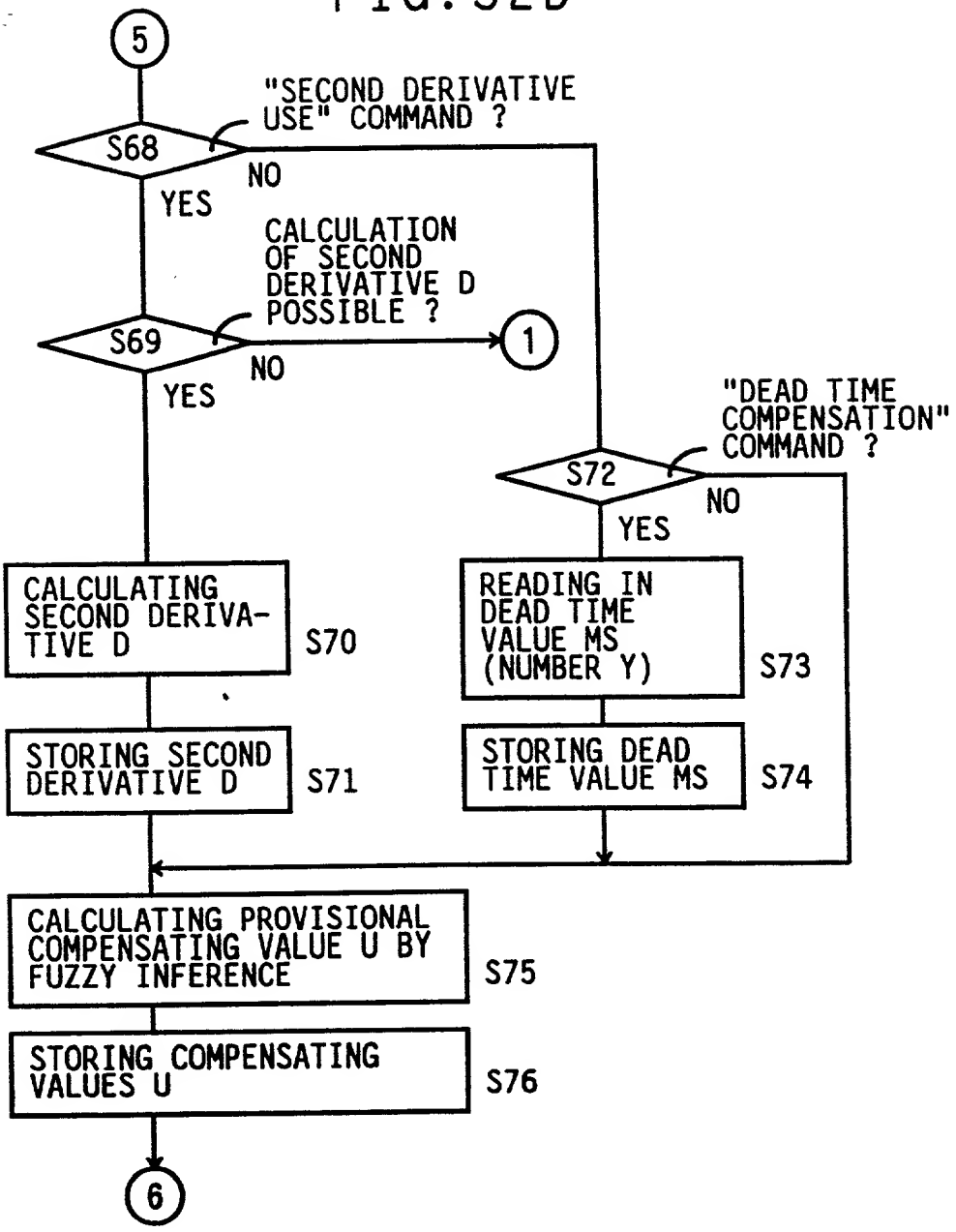

5
"SECOND DERIVATIVE USE" COMMAND ?
S68
NO
YES
CALCULATION OF SECOND DERIVATIVE D POSSIBLE ?
S69
NO
1
YES
"DEAD TIME COMPENSATION" COMMAND ?
S72
NO
YES
CALCULATING SECOND DERIVATIVE D
S70
READING IN DEAD TIME VALUE MS (NUMBER Y)
S73
STORING SECOND DERIVATIVE D
S71
STORING DEAD TIME VALUE MS
S74
CALCULATING PROVISIONAL COMPENSATING VALUE U BY FUZZY INFERENCE
S75
STORING COMPENSATING VALUES U
S76
6

FIG. 33

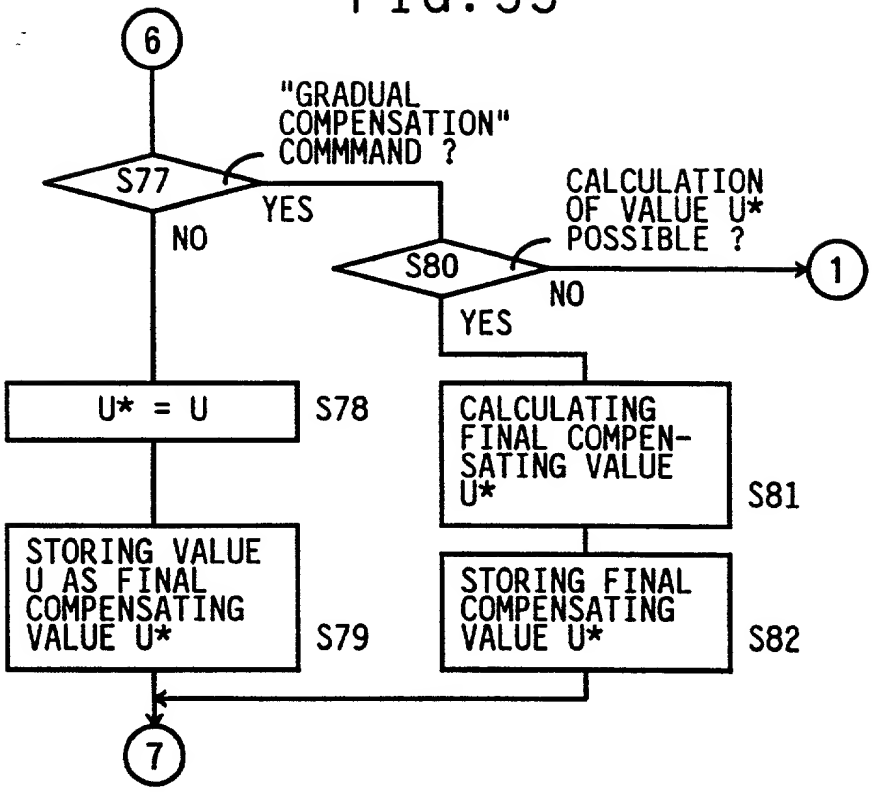

6
"GRADUAL COMPENSATION" COMMMAND ?
S77
YES
NO
CALCULATION OF VALUE U* POSSIBLE ?
S80
NO
1
YES
U* = U
S78
CALCULATING FINAL COMPEN-SATING VALUE U*
S81
STORING VALUE U AS FINAL COMPENSATING VALUE U*
S79
STORING FINAL COMPENSATING VALUE U*
S82
7

FIG. 34A

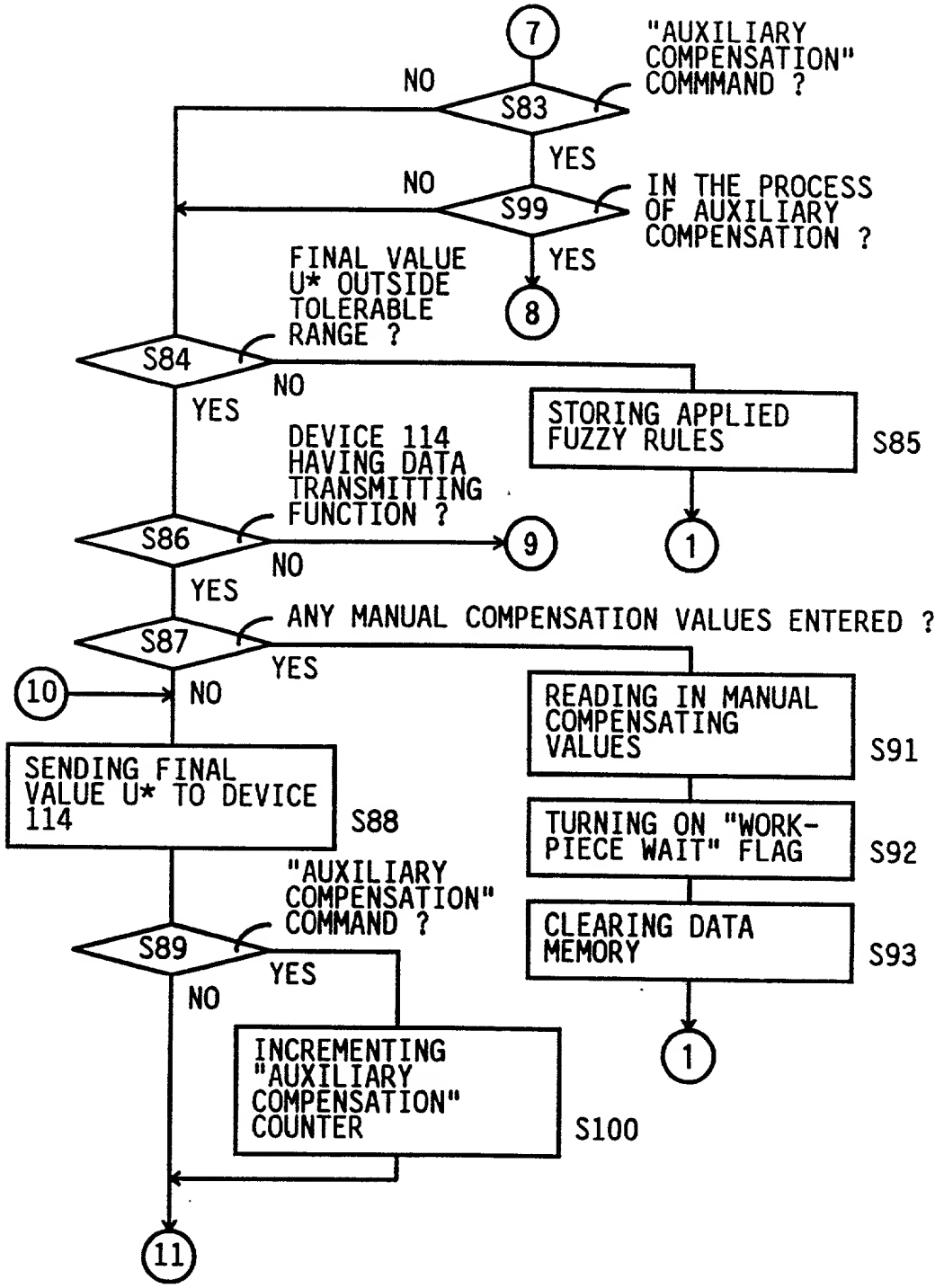

7
"AUXILIARY COMPENSATION" COMMMAND ?
S83
NO
YES
IN THE PROCESS OF AUXILIARY COMPENSATION ?
S99
NO
YES
8
FINAL VALUE U* OUTSIDE TOLERABLE RANGE ?
S84
NO
YES
STORING APPLIED FUZZY RULES
S85
1
DEVICE 114 HAVING DATA TRANSMITTING FUNCTION ?
S86
9
NO
YES
ANY MANUAL COMPENSATION VALUES ENTERED ?
S87
YES
10
NO
READING IN MANUAL COMPENSATING VALUES
S91
SENDING FINAL VALUE U* TO DEVICE 114
S88
TURNING ON "WORK-PIECE WAIT" FLAG
S92
"AUXILIARY COMPENSATION" COMMAND ?
S89
CLEARING DATA MEMORY
S93
YES
NO
1
INCREMENTING "AUXILIARY COMPENSATION" COUNTER
S100
11

FIG. 34B

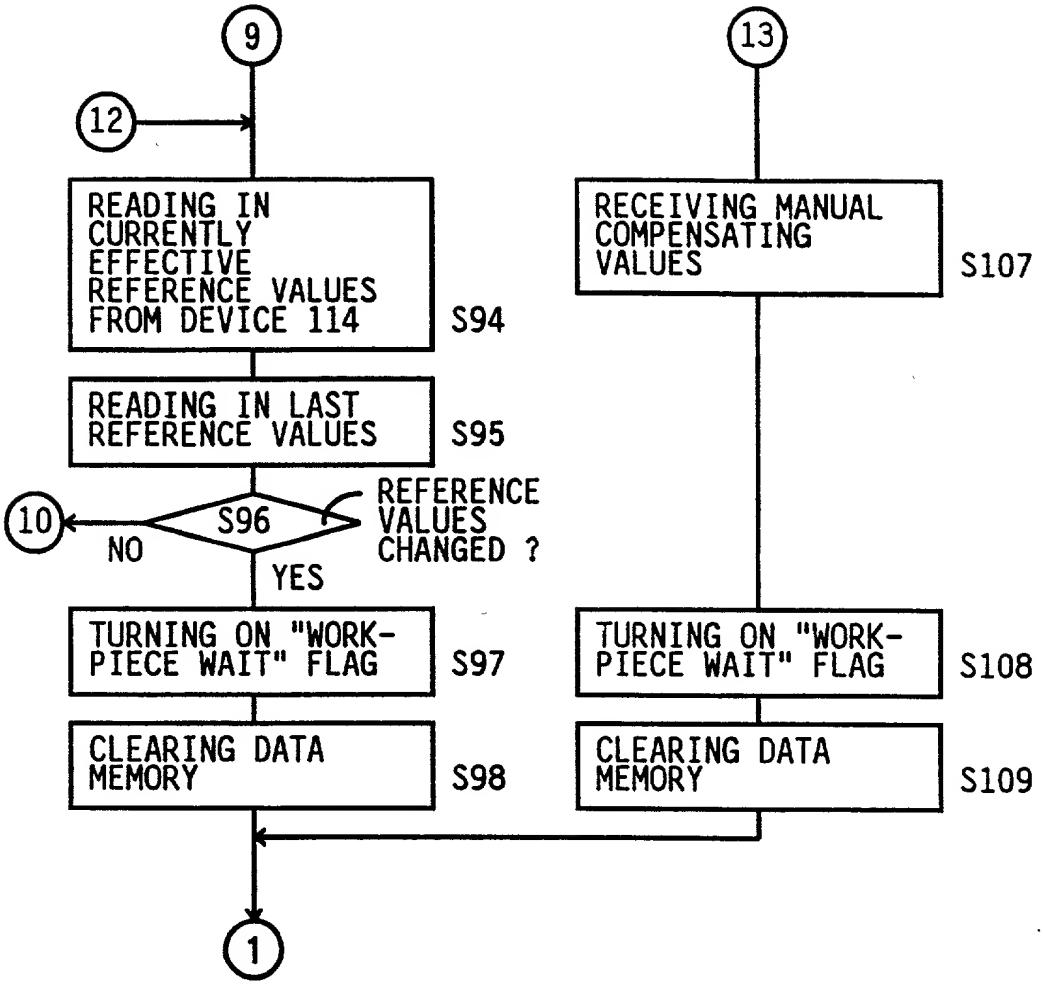

9
12
13
READING IN CURRENTLY EFFECTIVE REFERENCE VALUES FROM DEVICE 114
S94
READING IN LAST REFERENCE VALUES
S95
10
S96
REFERENCE VALUES CHANGED ?
NO
YES
TURNING ON "WORK-PIECE WAIT" FLAG
S97
CLEARING DATA MEMORY
S98
RECEIVING MANUAL COMPENSATING VALUES
S107
TURNING ON "WORK-PIECE WAIT" FLAG
S108
CLEARING DATA MEMORY
S109
1

FIG. 34C

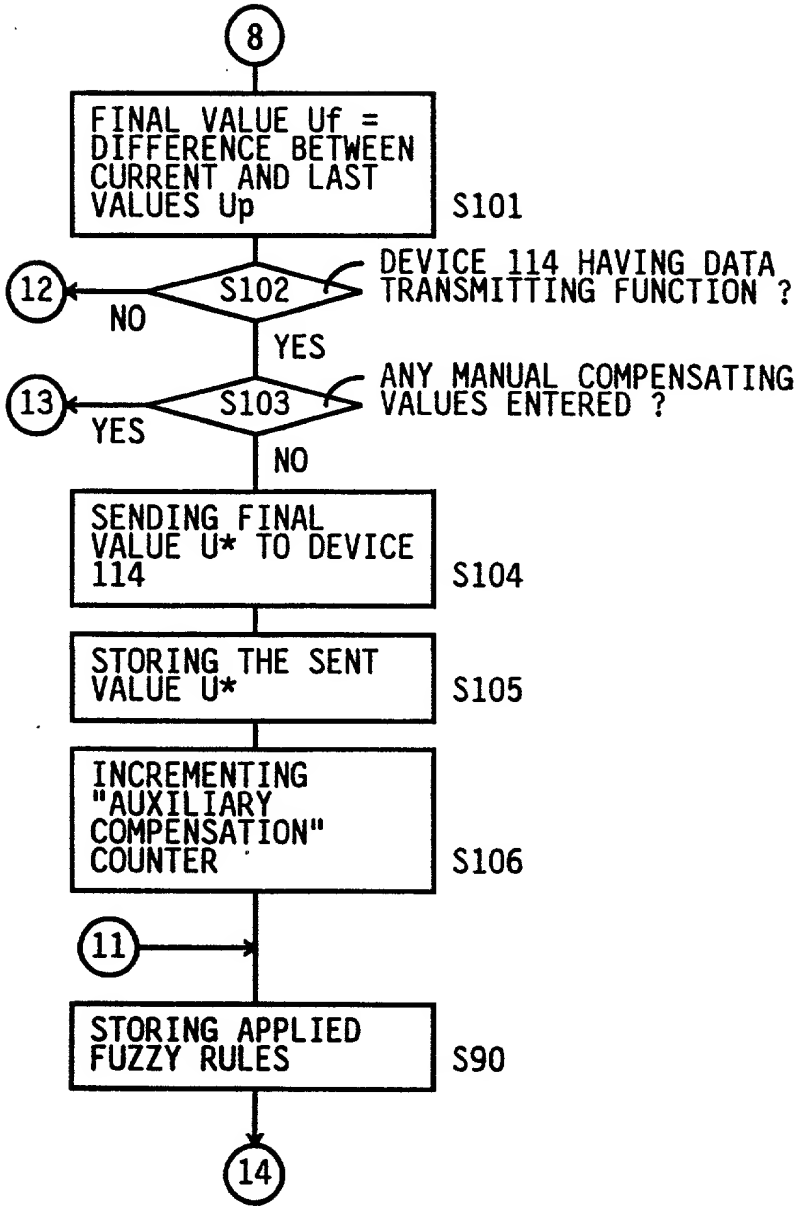

8
FINAL VALUE Uf = DIFFERENCE BETWEEN CURRENT AND LAST VALUES Up
S101
S102
DEVICE 114 HAVING DATA TRANSMITTING FUNCTION ?
12
NO
YES
S103
ANY MANUAL COMPENSATING VALUES ENTERED ?
13
YES
NO
SENDING FINAL VALUE U* TO DEVICE 114
S104
STORING THE SENT VALUE U*
S105
INCREMENTING "AUXILIARY COMPENSATION" COUNTER
S106
11
STORING APPLIED FUZZY RULES
S90
14

FIG. 35A

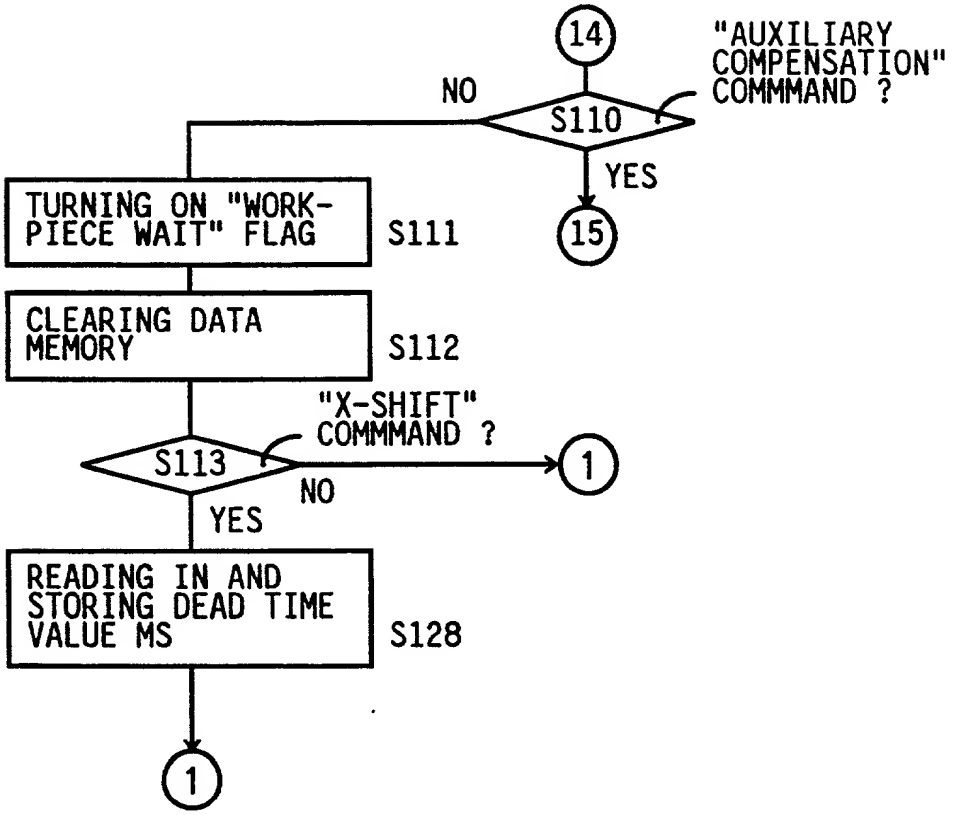

14
"AUXILIARY COMPENSATION" COMMMAND ?
NO
S110
YES
15
TURNING ON "WORK-PIECE WAIT" FLAG
S111
CLEARING DATA MEMORY
S112
"X-SHIFT" COMMMAND ?
S113
NO
1
YES
READING IN AND STORING DEAD TIME VALUE MS
S128
1

FIG. 35B

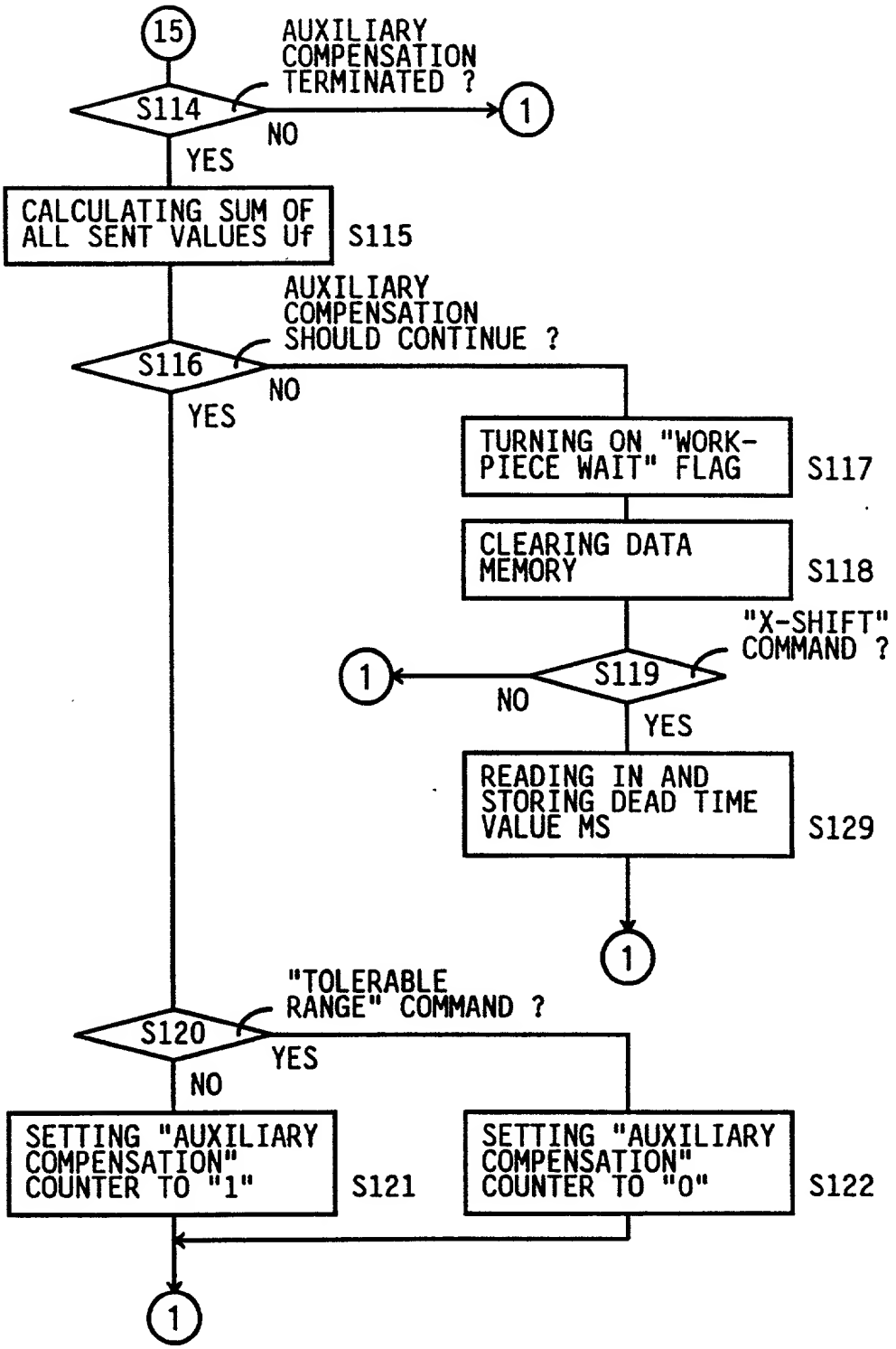

15
AUXILIARY COMPENSATION TERMINATED ?
S114
NO
1
YES
CALCULATING SUM OF ALL SENT VALUES Uf
S115
AUXILIARY COMPENSATION SHOULD CONTINUE ?
S116
NO
YES
TURNING ON "WORK-PIECE WAIT" FLAG
S117
CLEARING DATA MEMORY
S118
"X-SHIFT" COMMAND ?
S119
1
NO
YES
READING IN AND STORING DEAD TIME VALUE MS
S129
1
"TOLERABLE RANGE" COMMAND ?
S120
YES
NO
SETTING "AUXILIARY COMPENSATION" COUNTER TO "1"
S121
SETTING "AUXILIARY COMPENSATION" COUNTER TO "0"
S122
1

FIG. 36

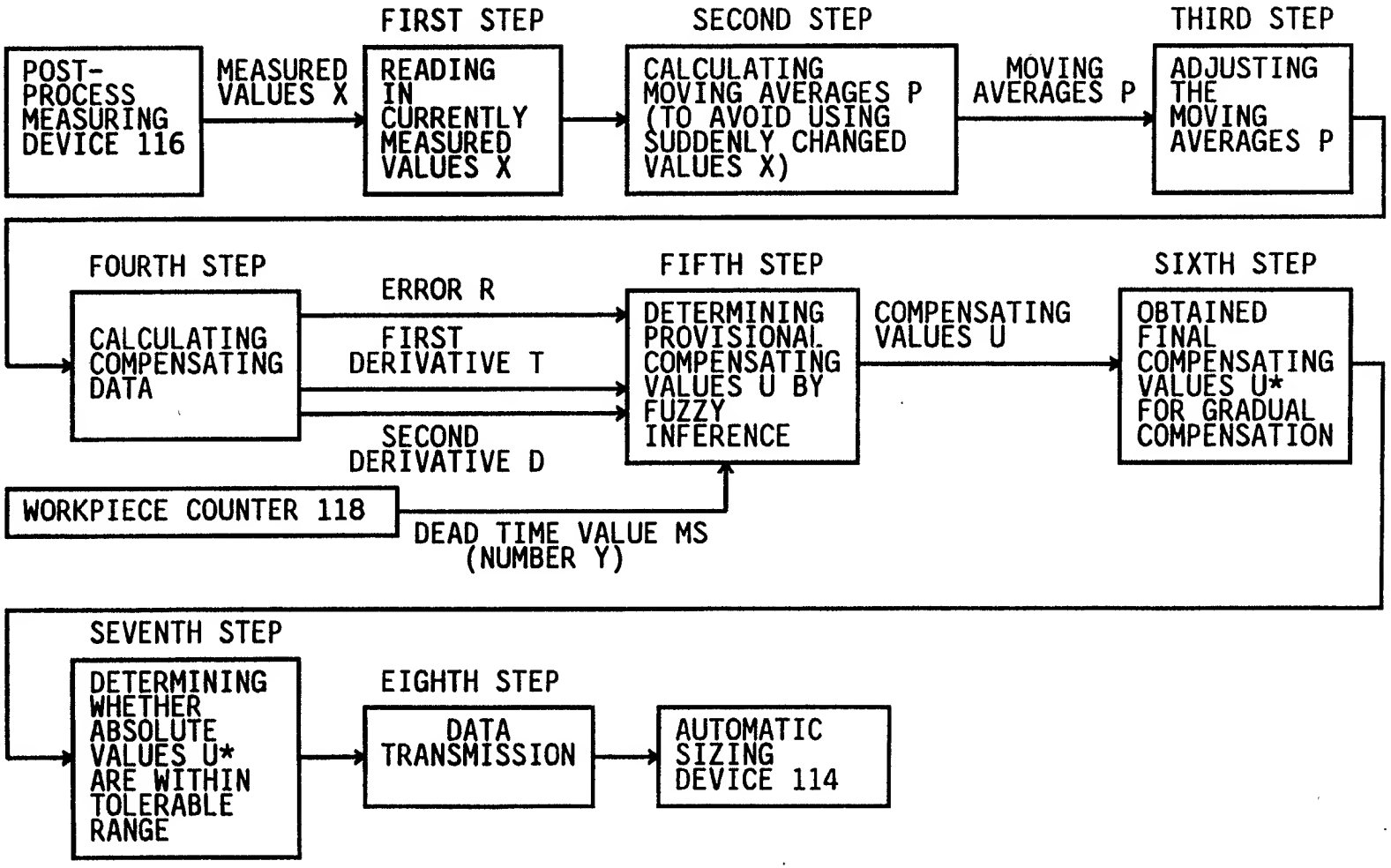
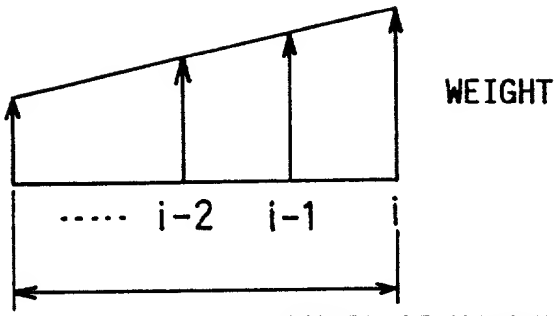

FIRST STEP
SECOND STEP
THIRD STEP
POST-PROCESS MEASURING DEVICE 116
MEASURED VALUES X
READING IN CURRENTLY MEASURED VALUES X
CALCULATING MOVING AVERAGES P (TO AVOID USING SUDDENLY CHANGED VALUES X)
MOVING AVERAGES P
ADJUSTING THE MOVING AVERAGES P
FOURTH STEP
FIFTH STEP
SIXTH STEP
CALCULATING COMPENSATING DATA
ERROR R
FIRST DERIVATIVE T
SECOND DERIVATIVE D
DETERMINING PROVISIONAL COMPENSATING VALUES U BY FUZZY INFERENCE
COMPENSATING VALUES U
OBTAINED FINAL COMPENSATING VALUES U* FOR GRADUAL COMPENSATION
WORKPIECE COUNTER 118
DEAD TIME VALUE MS (NUMBER Y)
SEVENTH STEP
EIGHTH STEP
DETERMINING WHETHER ABSOLUTE VALUES U* ARE WITHIN TOLERABLE RANGE
DATA TRANSMISSION
AUTOMATIC SIZING DEVICE 114

FIG. 37



K : NUMBER OF MEASURED VALUES TO OBTAIN MOVING AVERAGE

FIG. 38

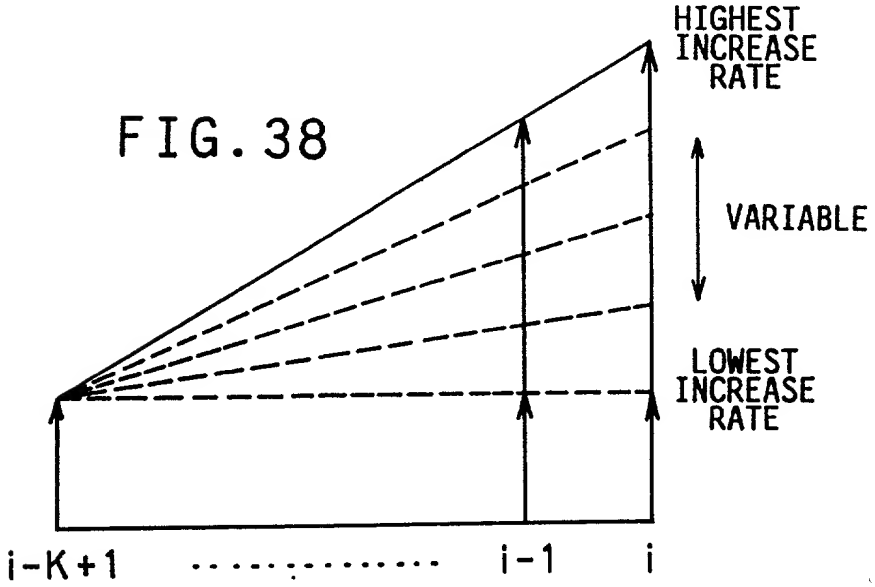


FIG. 39

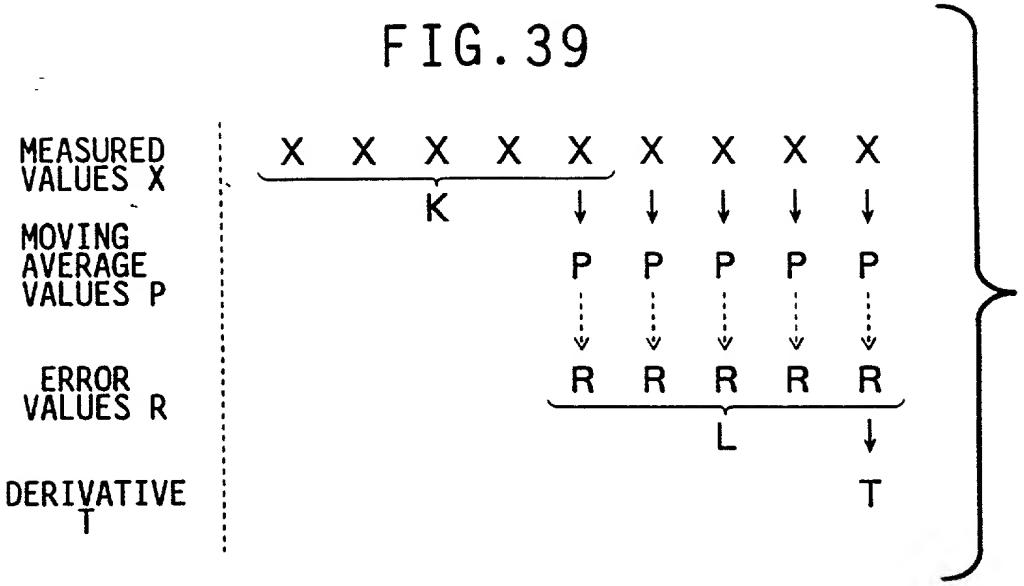

MEASURED VALUES X
MOVING AVERAGE VALUES P
ERROR VALUES R
DERIVATIVE T
X X X X X X X X X
K
P P P P P
R R R R R
L
T

FIG. 40

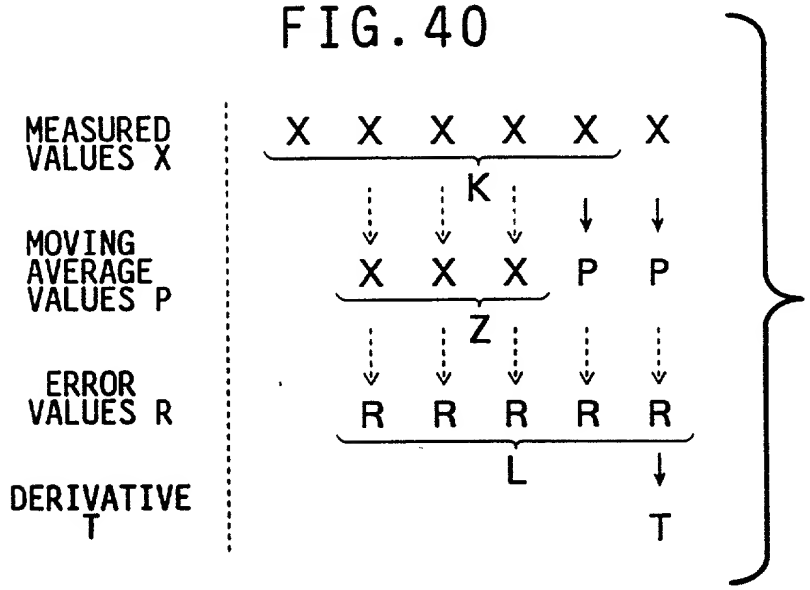

MEASURED VALUES X
MOVING AVERAGE VALUES P
ERROR VALUES R
DERIVATIVE T
X X X X X X
K
X X X P P
Z
R R R R R
L
T

FIG. 41

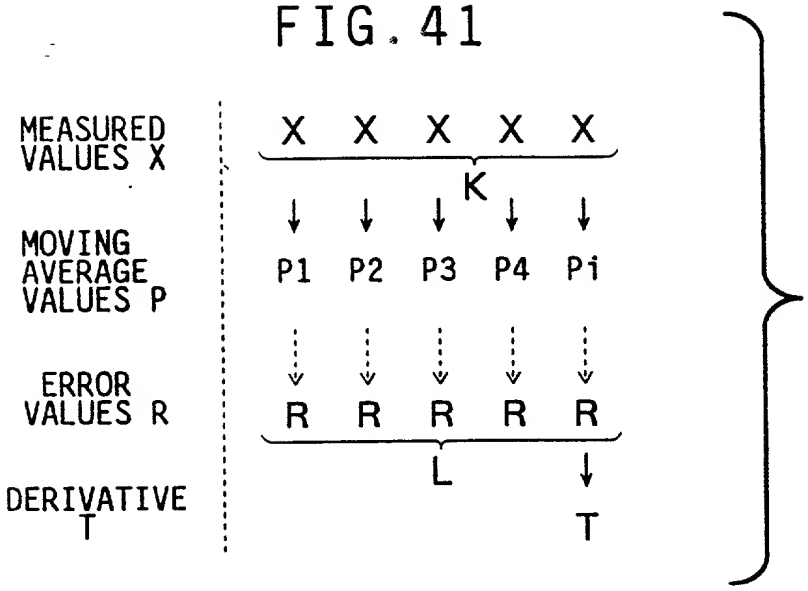

MEASURED VALUES X
X X X X X
K
MOVING AVERAGE VALUES P
P1 P2 P3 P4 Pi
ERROR VALUES R
R R R R R
L
DERIVATIVE T
T

FIG. 42

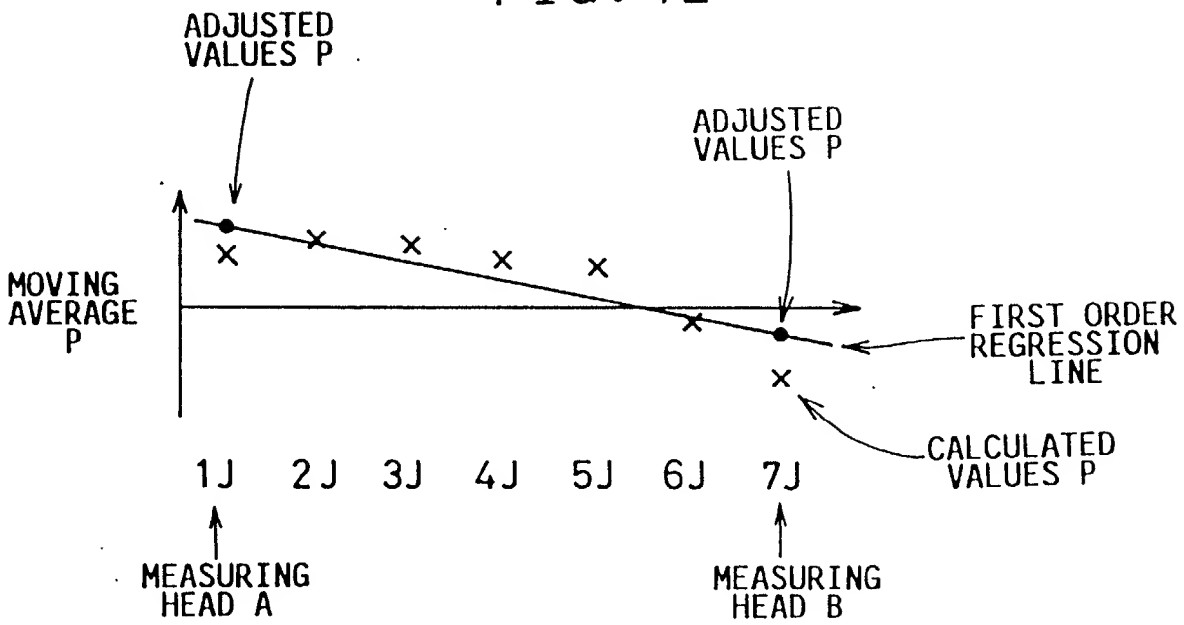

ADJUSTED VALUES P
ADJUSTED VALUES P
MOVING AVERAGE P
FIRST ORDER REGRESSION LINE
CALCULATED VALUES P
1J
2J
3J
4J
5J
6J
7J
MEASURING HEAD A
MEASURING HEAD B

FIG. 43

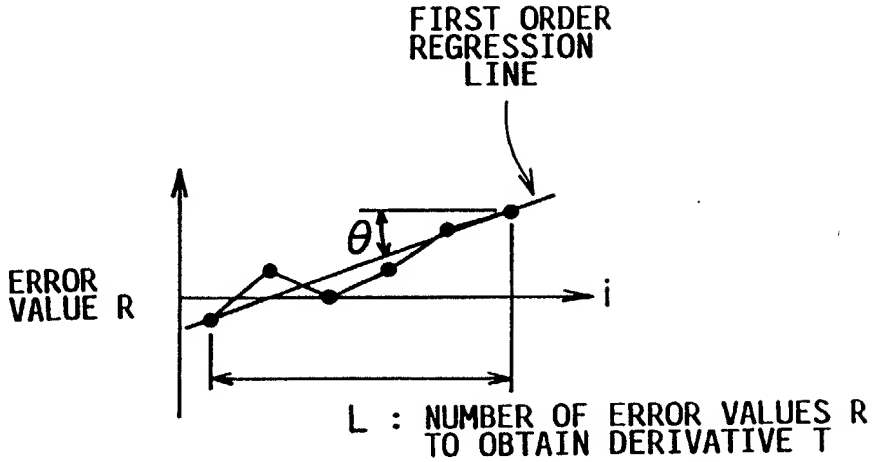


FIG. 44

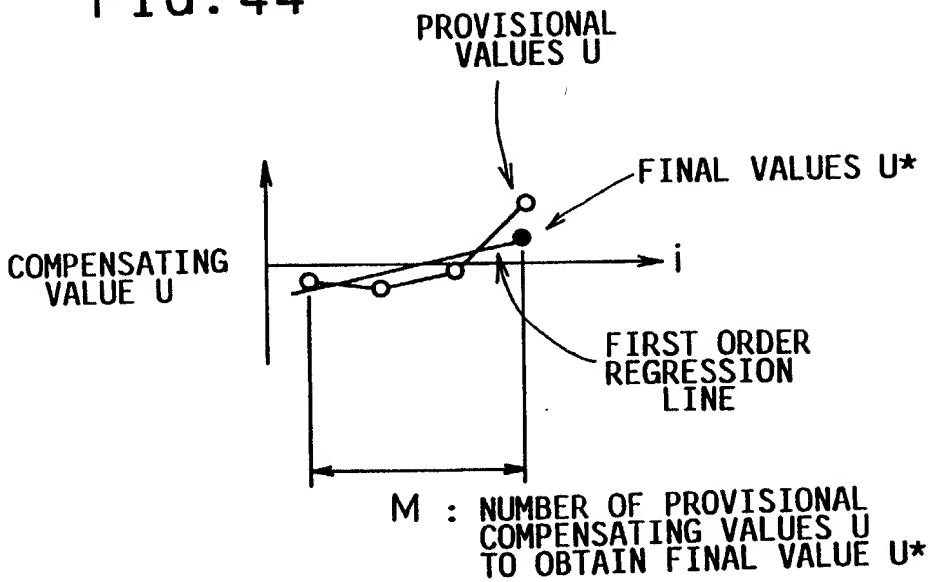


FIG. 45

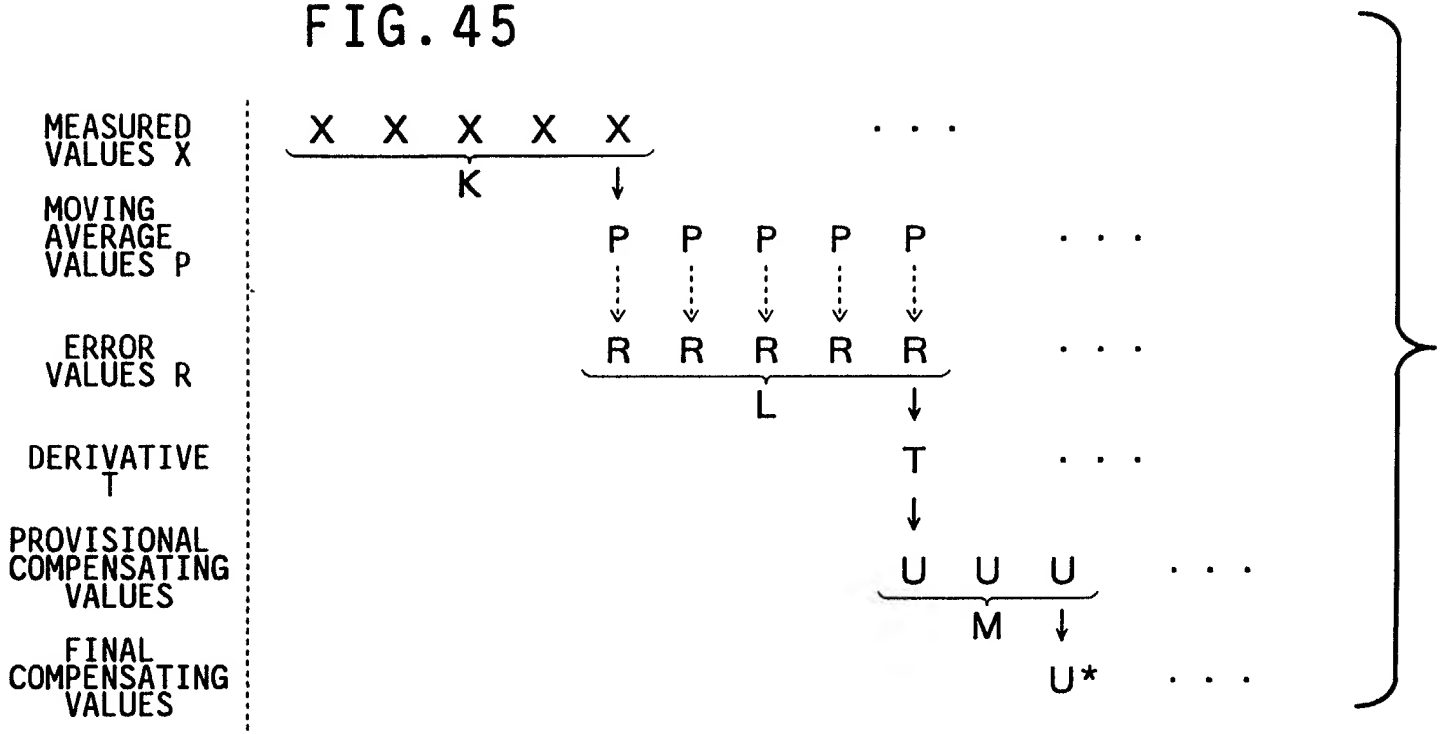


FIG. 46

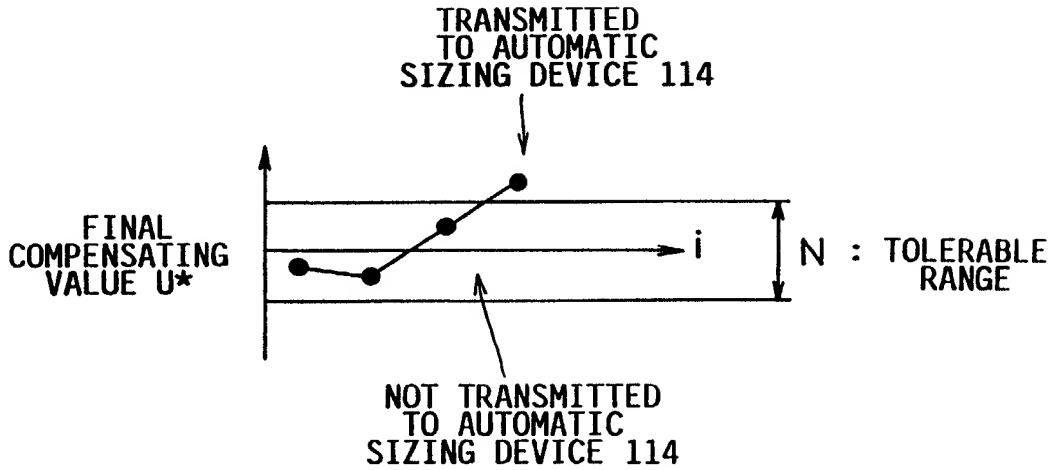

TRANSMITTED
TO AUTOMATIC
SIZING DEVICE 114
FINAL
COMPENSATING
VALUE U*
i
N : TOLERABLE
RANGE
NOT TRANSMITTED
TO AUTOMATIC
SIZING DEVICE 114

FIG. 47

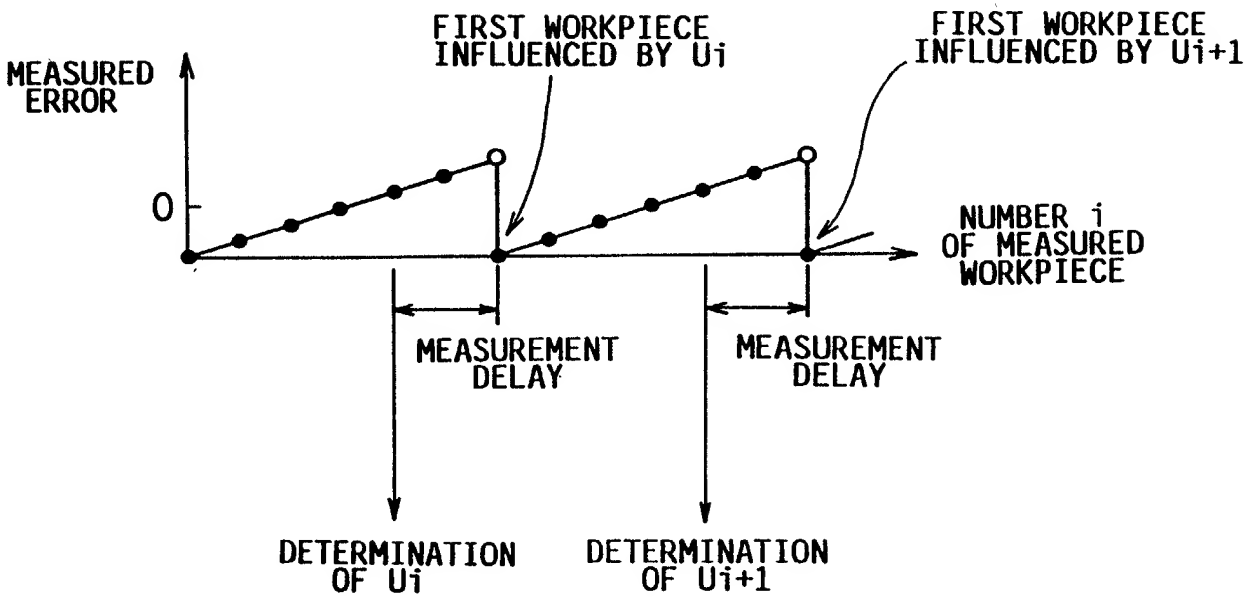

FIRST WORKPIECE INFLUENCED BY Ui
FIRST WORKPIECE INFLUENCED BY Ui+1
MEASURED ERROR
0
NUMBER i OF MEASURED WORKPIECE
MEASUREMENT DELAY
MEASUREMENT DELAY
DETERMINATION OF Ui
DETERMINATION OF Ui+1

FIG. 48

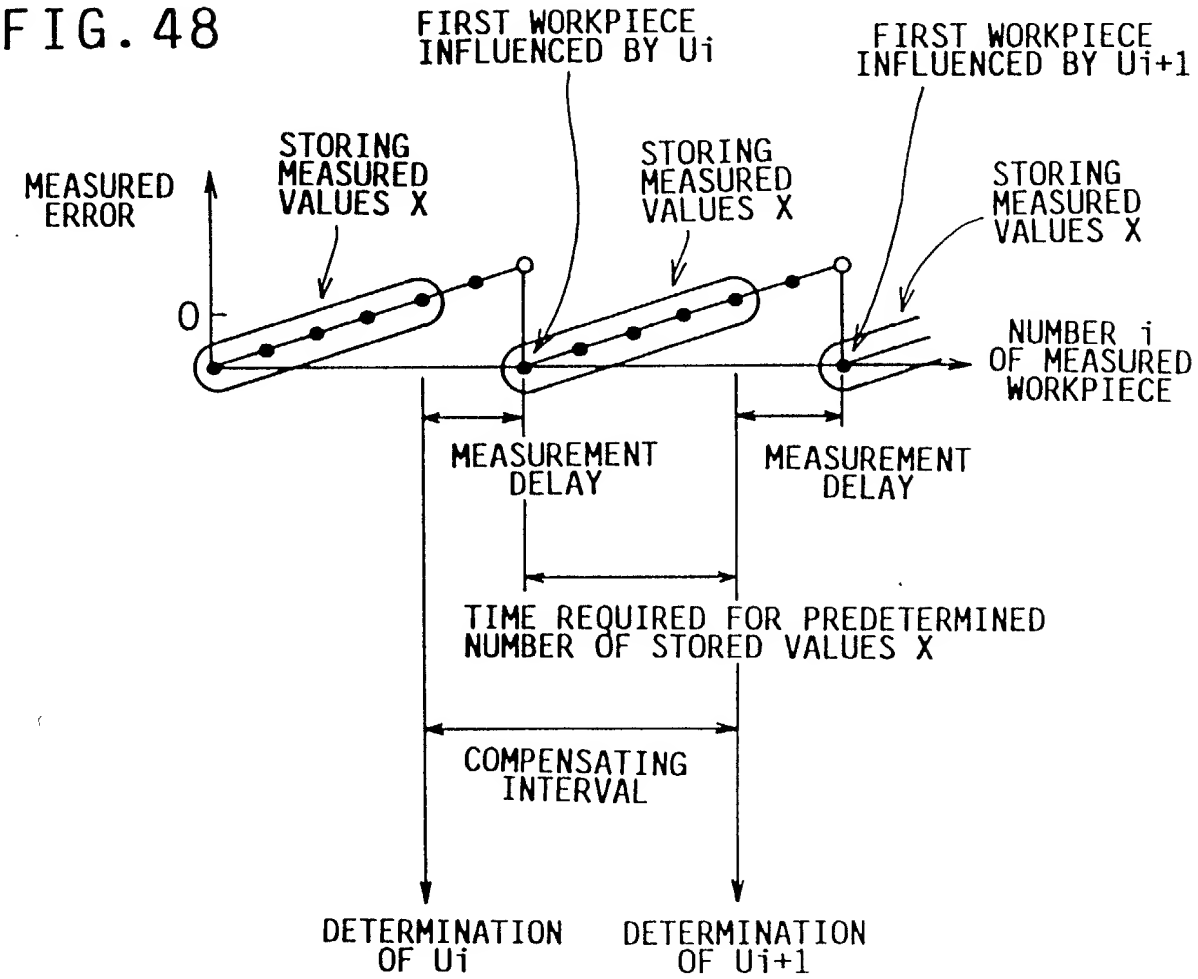

FIRST WORKPIECE INFLUENCED BY Ui
FIRST WORKPIECE INFLUENCED BY Ui+1
STORING MEASURED VALUES X
STORING MEASURED VALUES X
STORING MEASURED VALUES X
MEASURED ERROR
0
NUMBER i OF MEASURED WORKPIECE
MEASUREMENT DELAY
MEASUREMENT DELAY
TIME REQUIRED FOR PREDETERMINED NUMBER OF STORED VALUES X
COMPENSATING INTERVAL
DETERMINATION OF Ui
DETERMINATION OF Ui+1

FIG. 49

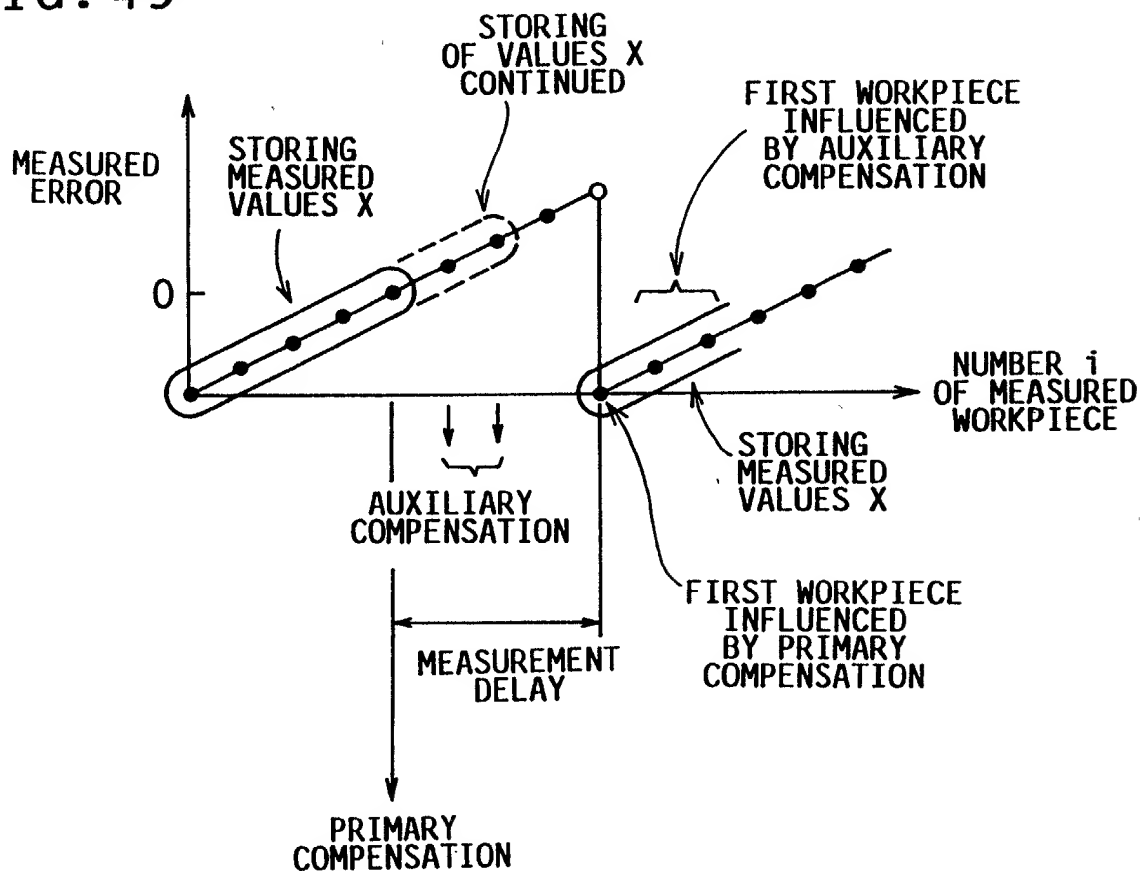
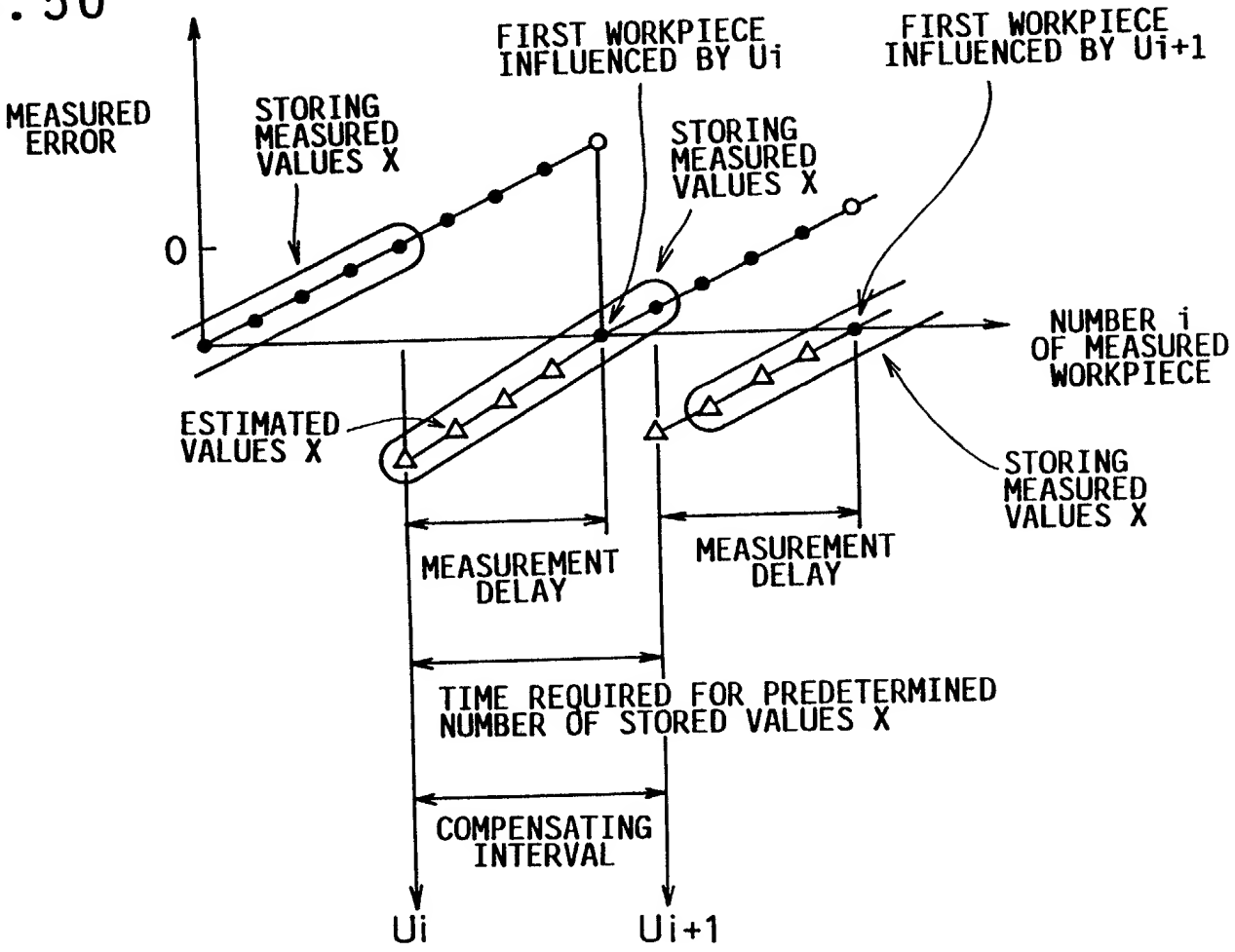


FIG. 50



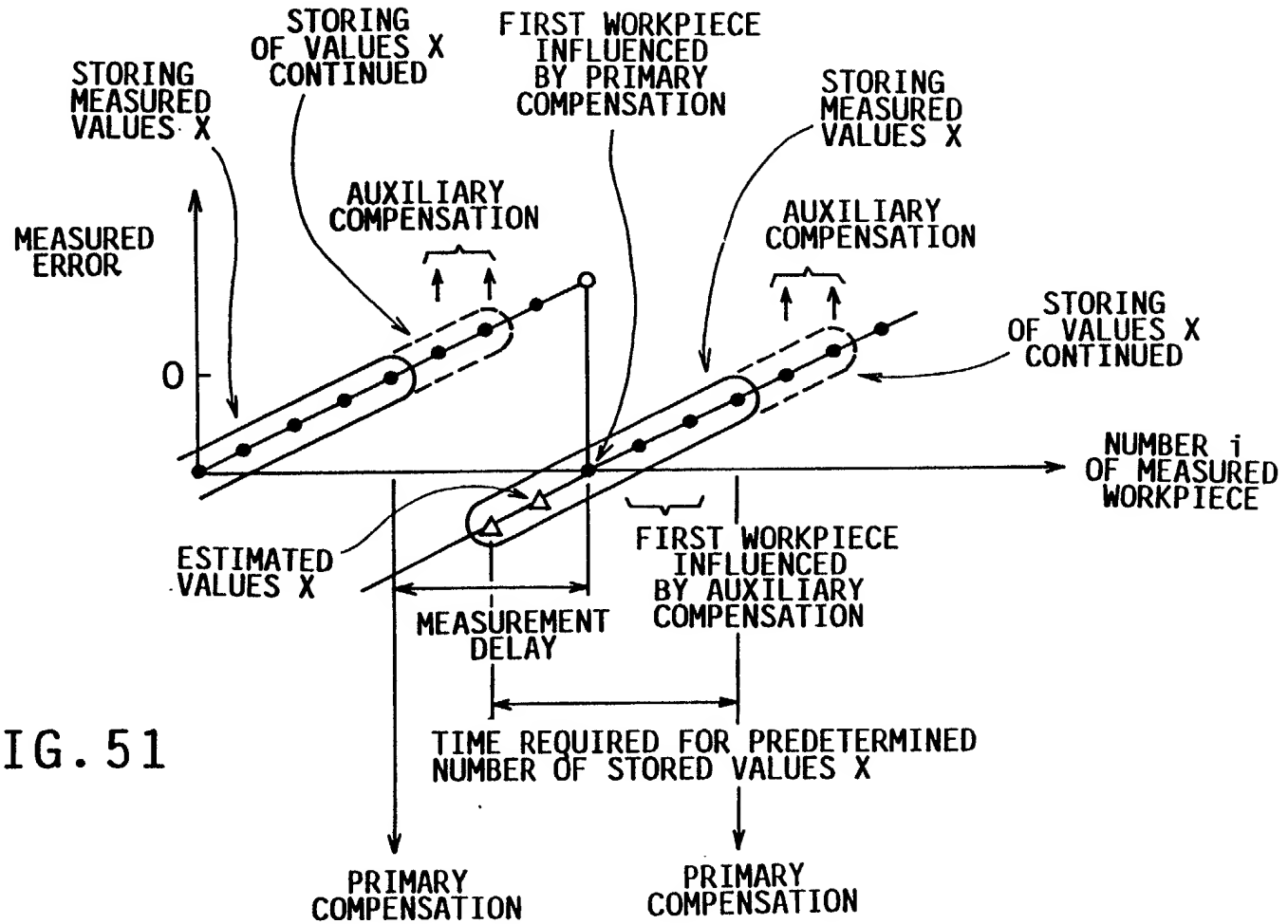

STORING MEASURED VALUES X
STORING OF VALUES X CONTINUED
FIRST WORKPIECE INFLUENCED BY PRIMARY COMPENSATION
STORING MEASURED VALUES X
AUXILIARY COMPENSATION
AUXILIARY COMPENSATION
MEASURED ERROR
0
STORING OF VALUES X CONTINUED
NUMBER i OF MEASURED WORKPIECE
ESTIMATED VALUES X
FIRST WORKPIECE INFLUENCED BY AUXILIARY COMPENSATION
MEASUREMENT DELAY
TIME REQUIRED FOR PREDETERMINED NUMBER OF STORED VALUES X
PRIMARY COMPENSATION
PRIMARY COMPENSATION

FIG. 51

FIG. 52

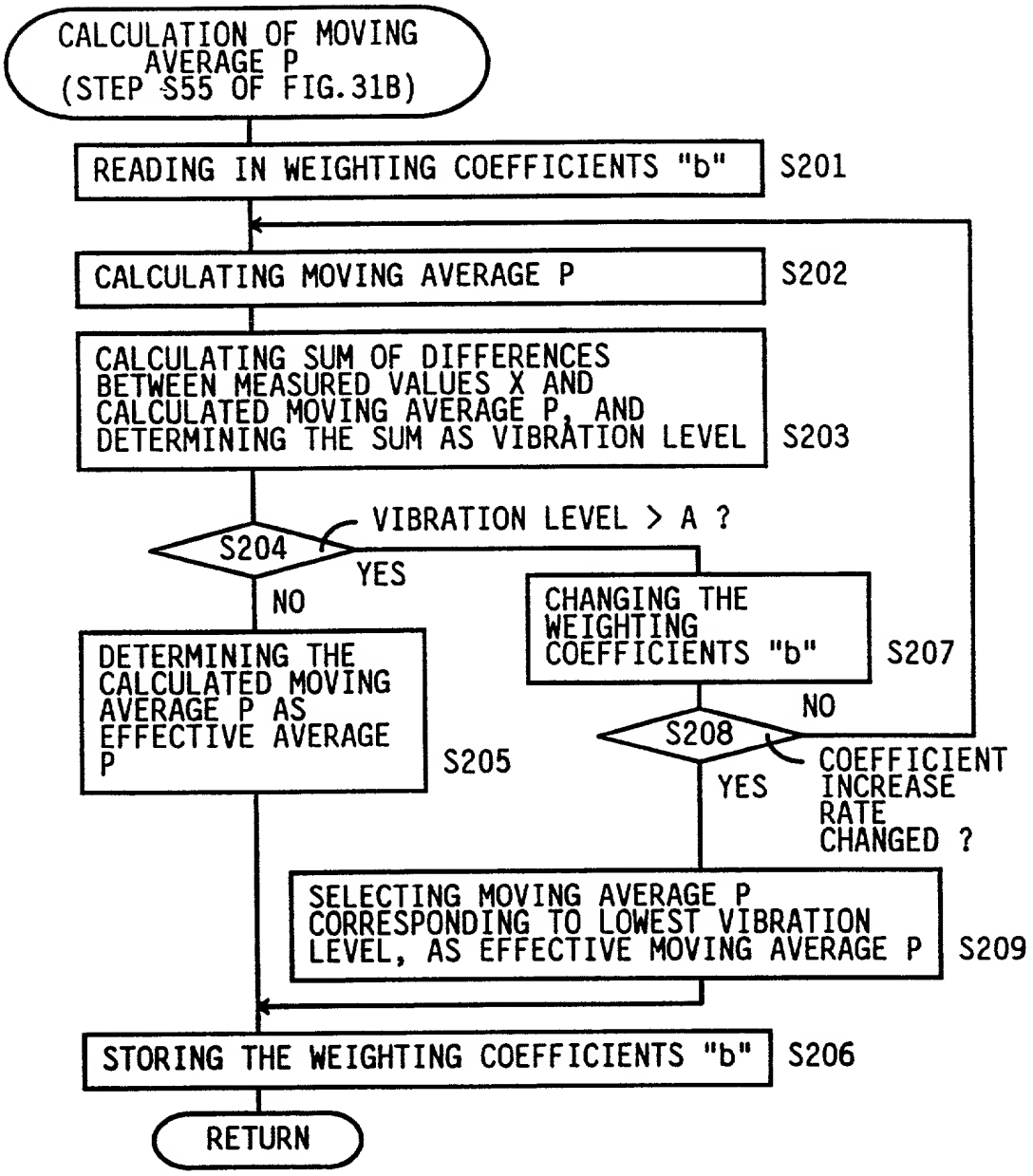

CALCULATION OF MOVING AVERAGE P (STEP S55 OF FIG. 31B)
READING IN WEIGHTING COEFFICIENTS "b"
S201
CALCULATING MOVING AVERAGE P
S202
CALCULATING SUM OF DIFFERENCES BETWEEN MEASURED VALUES X AND CALCULATED MOVING AVERAGE P, AND DETERMINING THE SUM AS VIBRATION LEVEL
S203
S204
VIBRATION LEVEL > A ?
YES
NO
DETERMINING THE CALCULATED MOVING AVERAGE P AS EFFECTIVE AVERAGE P
S205
CHANGING THE WEIGHTING COEFFICIENTS "b"
S207
S208
NO
YES
COEFFICIENT INCREASE RATE CHANGED ?
SELECTING MOVING AVERAGE P CORRESPONDING TO LOWEST VIBRATION LEVEL, AS EFFECTIVE MOVING AVERAGE P
S209
STORING THE WEIGHTING COEFFICIENTS "b"
S206
RETURN

FIG. 53

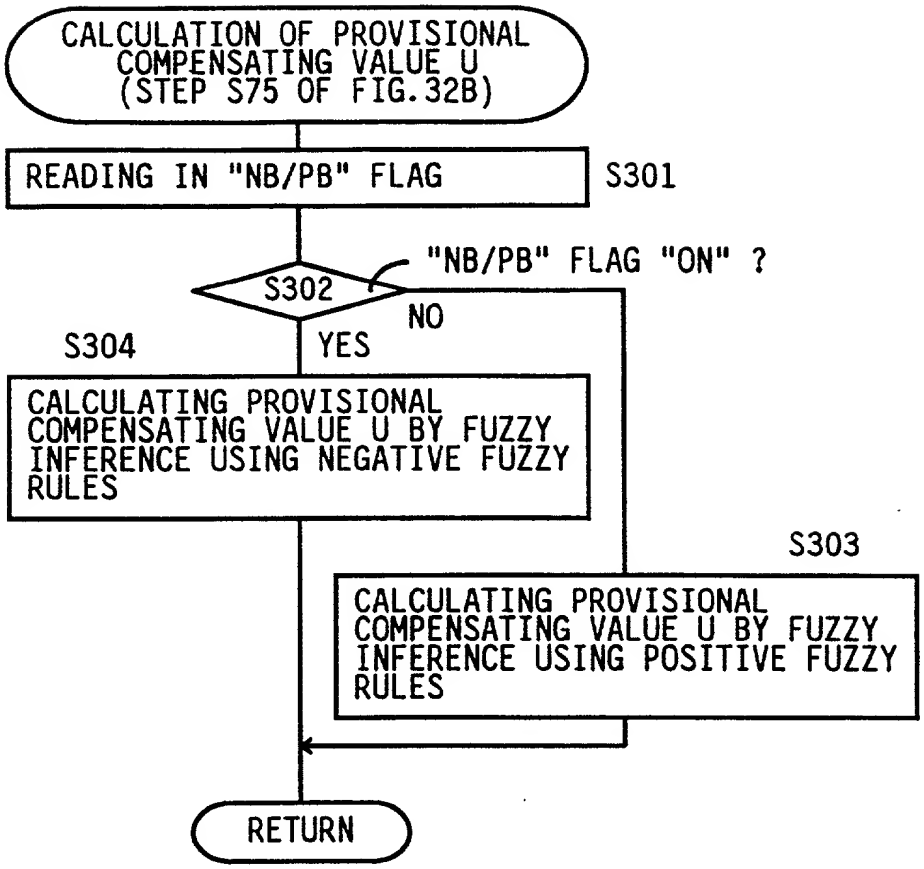
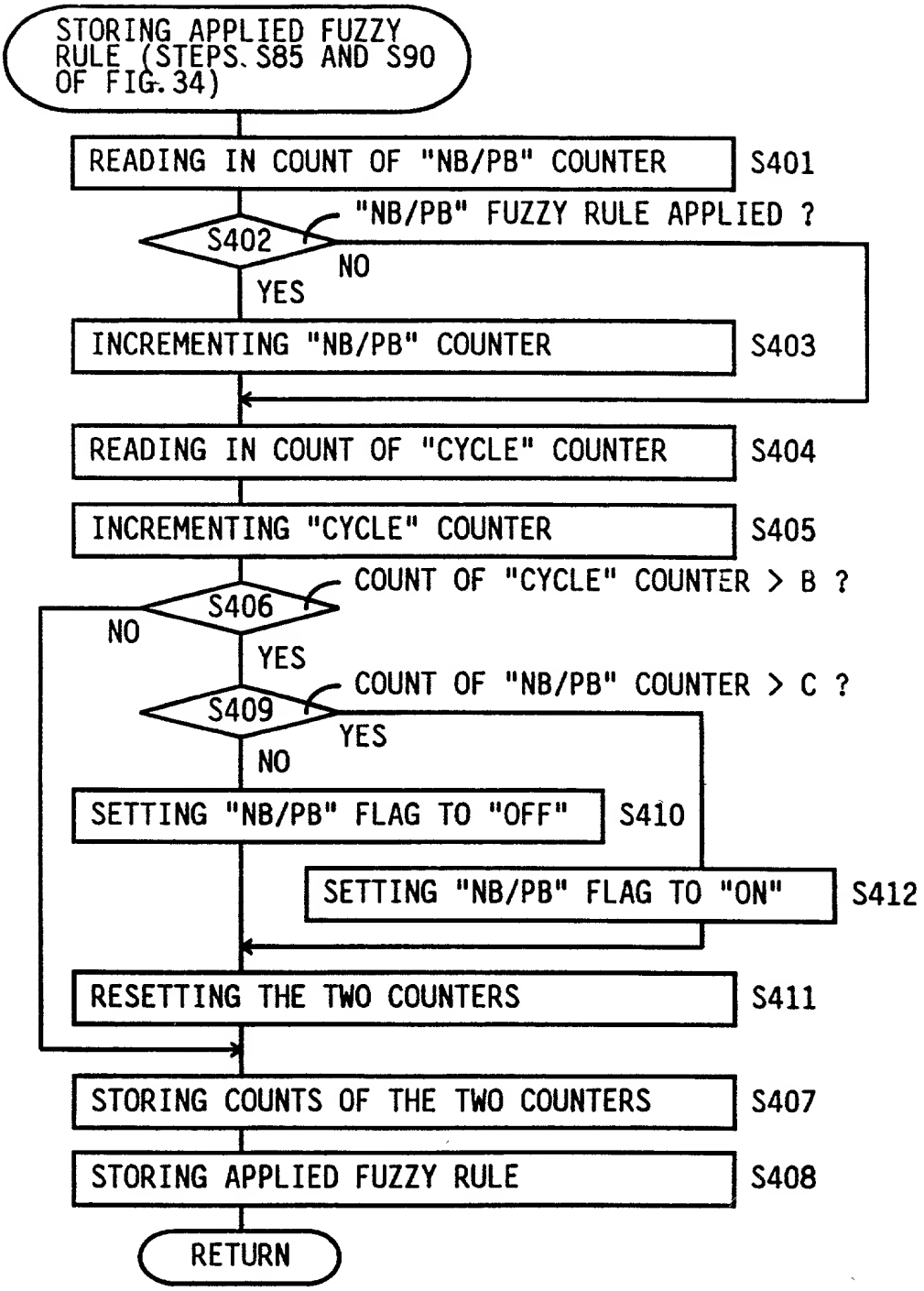

CALCULATION OF PROVISIONAL COMPENSATING VALUE U (STEP S75 OF FIG. 32B)
READING IN "NB/PB" FLAG
S301
"NB/PB" FLAG "ON" ?
S302
NO
YES
S304
CALCULATING PROVISIONAL COMPENSATING VALUE U BY FUZZY INFERENCE USING NEGATIVE FUZZY RULES
S303
CALCULATING PROVISIONAL COMPENSATING VALUE U BY FUZZY INFERENCE USING POSITIVE FUZZY RULES
RETURN

FIG. 54


STORING APPLIED FUZZY RULE (STEPS S85 AND S90 OF FIG. 34)
READING IN COUNT OF "NB/PB" COUNTER
S401
S402
"NB/PB" FUZZY RULE APPLIED ?
NO
YES
INCREMENTING "NB/PB" COUNTER
S403
READING IN COUNT OF "CYCLE" COUNTER
S404
INCREMENTING "CYCLE" COUNTER
S405
S406
COUNT OF "CYCLE" COUNTER > B ?
NO
YES
S409
COUNT OF "NB/PB" COUNTER > C ?
YES
NO
SETTING "NB/PB" FLAG TO "OFF"
S410
SETTING "NB/PB" FLAG TO "ON"
S412
RESETTING THE TWO COUNTERS
S411
STORING COUNTS OF THE TWO COUNTERS
S407
STORING APPLIED FUZZY RULE
S408
RETURN